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ARKANSAS-RED RIVER BASINS WATER QUALITY CONSERVATION. APPENDIX. VOLUME I: THE MINERAL POLLUTION PROBLEM AND PROPOSED SOLUTIONS

Public Health Service
Washington, D. C.

June 1964

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Arkansas-Red River Basins

WATER QUALITY CONSERVATION

APPENDIX

VOLUME I - THE MINERAL POLLUTION PROBLEM AND PROPOSED SOLUTIONS

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U. S. DEPARTMENT OF
HEALTH, EDUCATION, AND WELFARE
Public Health Service

Arkansas-Red River Basins

WATER
QUALITY
CONSERVATION

APPENDIX
VOLUME I - THE MINERAL POLLUTION PROBLEM AND PROPOSED SOLUTIONS

An Intensive Study and Investigation of Mineral
Pollution and its Causes, Both Natural and
Manmade, in the Basins of the Arkansas
and Red Rivers, Together with Proposed
Solutions

Details of illustrations in
this document may be better
studied on microfiche.

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Division of Water Supply and Pollution Control
Washington, D.C. 20201
June 1964

I-a

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I. DESCRIPTION OF THE BASINS

Geography

Location and Drainage

The Arkansas and Red River basins are located in the southwestern and central plains regions of the United States and encompass approximately 8 percent of the country's land area, containing all of the State of Oklahoma and portions of the States of Colorado, New Mexico, Kansas, Texas, Missouri, Arkansas, and Louisiana. [1] The combined basins drain a crescent-shaped area of about 254,000 square miles. [2] (See Location Map - Figure I-1 following page VI-21.)

The Arkansas River rises high in the Southern Rocky Mountains near Leadville, Colorado. It meanders southeasterly through eastern Colorado, Kansas, Oklahoma, and Arkansas and enters the Mississippi River near Arkansas City, Arkansas draining about 160,000 square miles. In the river's first 100-mile reach, the Arkansas is a typical mountain stream flowing through deep gorges and precipitous terrain. Downstream from Canon City, Colorado, the stream flows across broad plains to its junction with the Mississippi River. The Arkansas River, as well as its tributaries, the Cimarron, Canadian, and North Canadian Rivers flow generally eastward across the High Plains. Large flows are contributed to the Arkansas River by the Verdigris and Grand (Neosho) Rivers. Minor tributaries to the Arkansas River which rise in the Ozark-Ouachita Highlands are swift flowing mountain streams. The lower Arkansas River meanders through a wide belt of alluvial flood plains broken by occasional old river banks and stream terraces in eastern Arkansas.

The origin of the Red River is in the High Plains area of northeastern New Mexico and the Panhandle of Texas. It flows easterly through the Panhandle, forms the boundary between Texas and Oklahoma and then continues through southwestern Arkansas into Louisiana, joining the Mississippi River near Angola, Louisiana. The river generally displays low and unstable banks. It drains an area of some 92,000 square miles. Numerous tributaries which rise in the southern Ouachita Mountains and the hilly areas to the west, including Boggy Creek, the Kiamichi River, and Little River, contribute to the substantially increased flows of the Red River in eastern Oklahoma and western Arkansas. The Ouachita River, the major downstream tributary, rises in the Ouachita Mountains and flows through the hilly uplands of southeastern Arkansas and the alluvial valley of the Mississippi River before entering the Red River just above its mouth.

Physiography

The source area of the Arkansas River basin is in the Sangre de Cristo, Sawatch, and Front ranges of the Southern Rocky Mountains of Colorado and New Mexico where elevations generally range between 8,000 and 10,000 feet above mean sea level and some peaks rise above 14,000 feet. 1/ A piedmont and plains belt east of the higher ranges extends from 50 to 100 miles. It includes linear hills and valleys parallel with and near the mountains, and farther east, plateaus and moderately dissected plains above which volcanic peaks rise. The streams, which flow through canyons and gorges at the higher elevations, become meandering rivers as they reach the adjoining plains.

Moving eastward, the almost unbroken surface of the High Plains extends for many miles diminishing gradually in elevation from 5,000 feet to less than 2,500 feet at the eastern edge of the plains. The High Plains become more dissected by stream valleys and give way to the Central Lowland in central Kansas and east of the Panhandle areas of Texas and Oklahoma. In eastern Kansas, Oklahoma, and Texas, elevations are generally in the range from 500 to 1,000 feet. Minor relief in the Lowland Plains is provided by the Arbuckle and Wichita Mountains in south-central and southwestern Oklahoma, the Flint Hills in southeastern Kansas, and the Sandstone Hills in eastern Oklahoma. The Ozark-Ouachita Highlands in Arkansas, Missouri, and extreme eastern Oklahoma flank the Arkansas River.

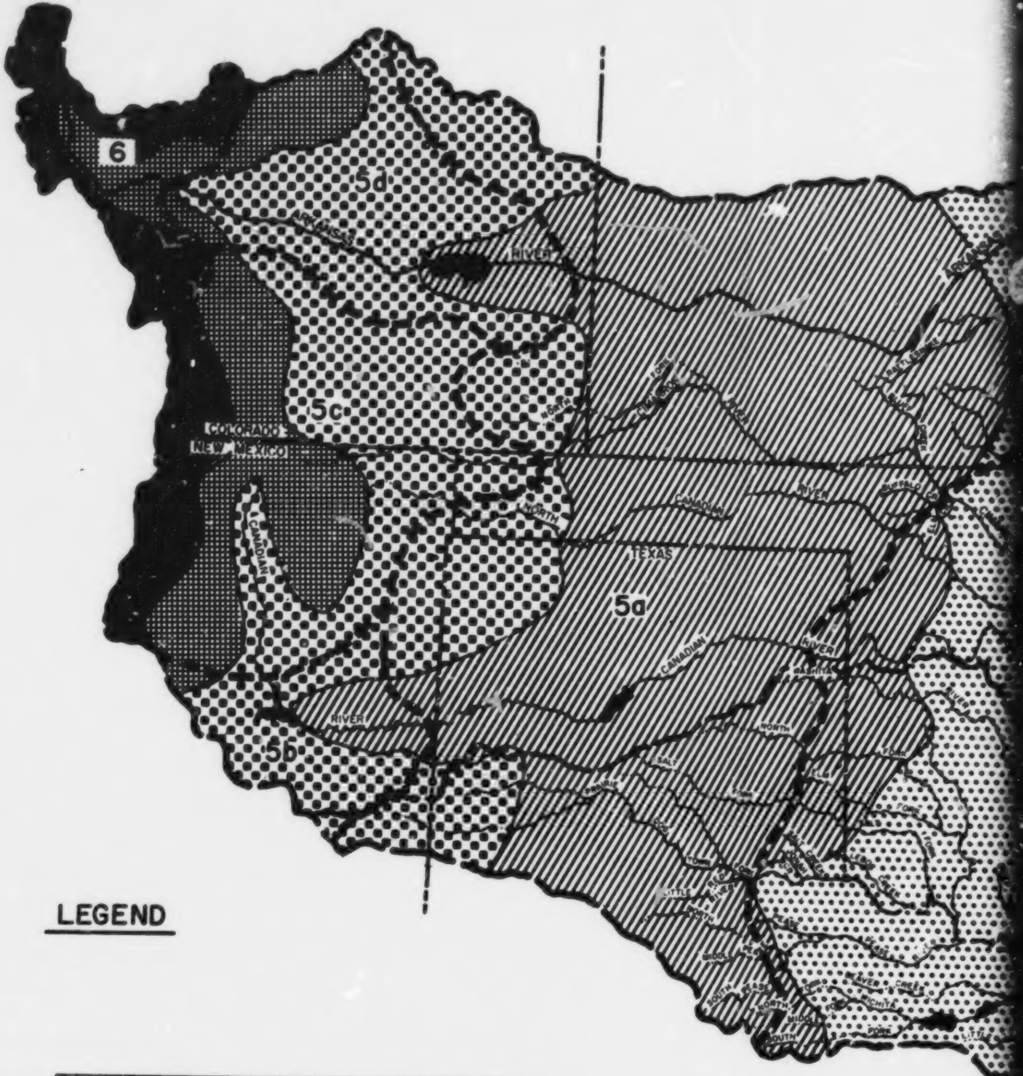
After the Red River flows through the Central Lowland, it meanders through the low and gently rolling Coastal Plain at elevations generally less than 500 feet.

In summary, the principal surface features of the Arkansas-Red River basins are: (1) a small area of high mountains to the west; (2) a large area of low mountains which rise abruptly from the Coastal and Mississippi Alluvial Plains in the east; and (3) a broad expanse of interior lowland sloping gradually from west to east, broken locally by escarpments, hills, and the relics of old eroded mountains between the two mountain areas. (See Figure I-2.)

Soils and Vegetation

Forests cover the humid eastern one-third of the basins. Upland hardwood is found in the Ozark Mountains and Arkansas Valley area. Southern pine and hardwood forests extend over the Ouachita Mountains and Coastal Plain, and river bottom forests occur on the alluvial plain and terraces of lower river reaches. The soils of the mountain and Coastal Plain area under the mixed coniferous and hardwood forests are somewhat acid and exhibit a relatively low organic matter content when compared to grassland soils. Surface

2


6
5d
5c
5b
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COLORADO
NEW MEXICO
TEXAS
ARKANSAS
RIVER
CANADIAN
RIVER
NORTH
CANADIAN
RIVER
WASHITA
NORTH
ARKANSAS

LEGEND

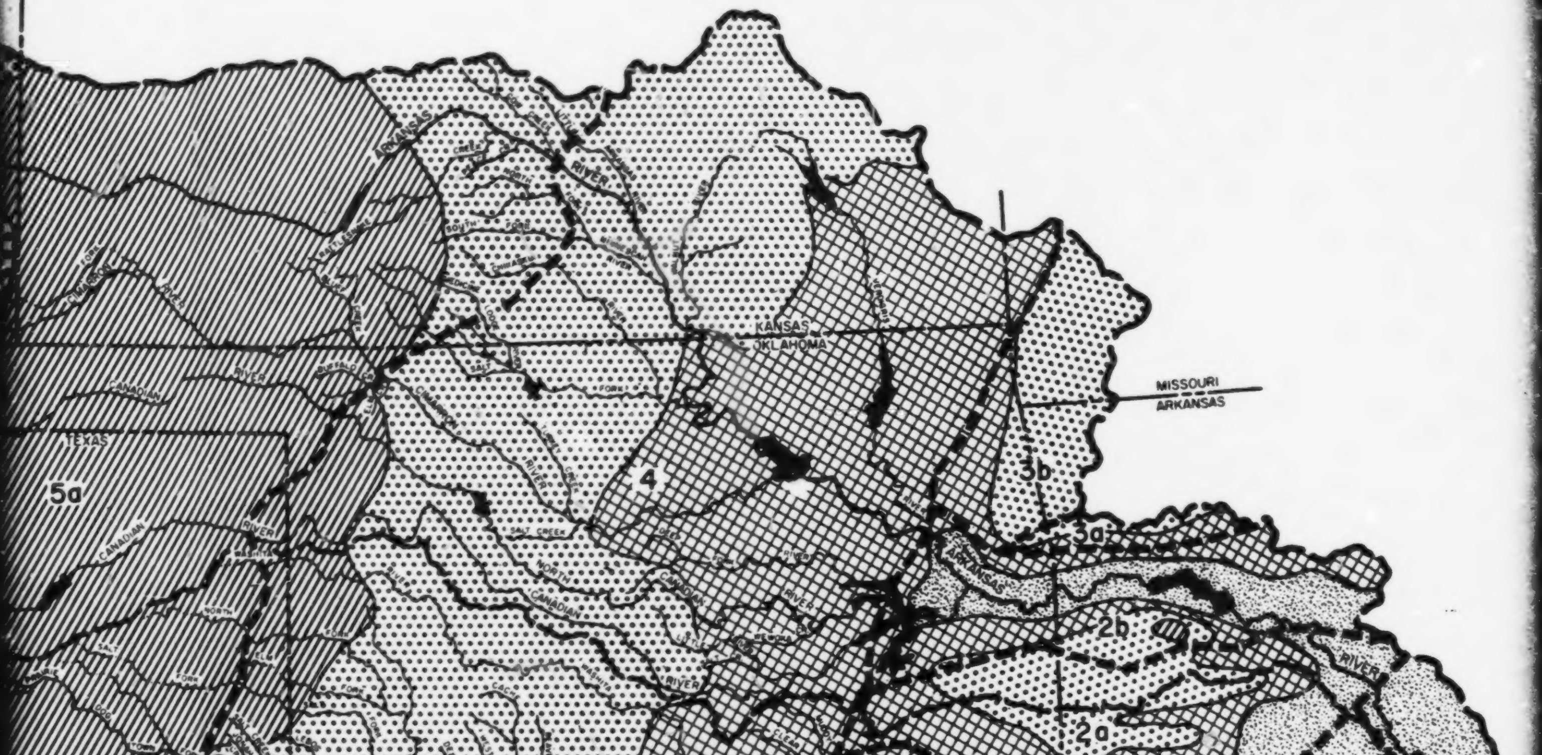
GENERAL ELEVATION
(Feet above mean sea level)

- ■ 8000—14000+
- ▦ 6000—8000
- ▩ 4000—6000
- ▨ 2000—4000
- ⁘ 1000—2000
- ▧ 500—1000
- ░ 100 — 500
- ⋯ 0—100

Province	Section
1. Coastal Plain	a. Mississippi Alluvial Plain b. West Gulf Coastal Plain
2. Ouachita Province	a. Ouachita b. Arkansas Valley
3. Ozark Plateaus	a. Boston "Mountains" b. Springfield — Salem Plateaus
4. Central Lowland	a. Osage Plains
5. Great Plains Province	a. Plains b. Pecos Valley c. Raton Section d. Colorado Piedmont
6. Southern Rocky Mountains	

A

769-560 O-65 (Face p. I-2)


ARKANSAS
RIVER
CANADIAN
RIVER
KANSAS
OKLAHOMA
MISSOURI
ARKANSAS
TEXAS
5a
4
3b
3a
2b
2a
1b
1a
SALT CREEK
NORTH
CANADIAN
RIVER
WASHITA
ARKANSAS
RIVER
RED
RIVER
RED
RIVER
ARKANSAS
LOUISIANA
SCALE IN MILES
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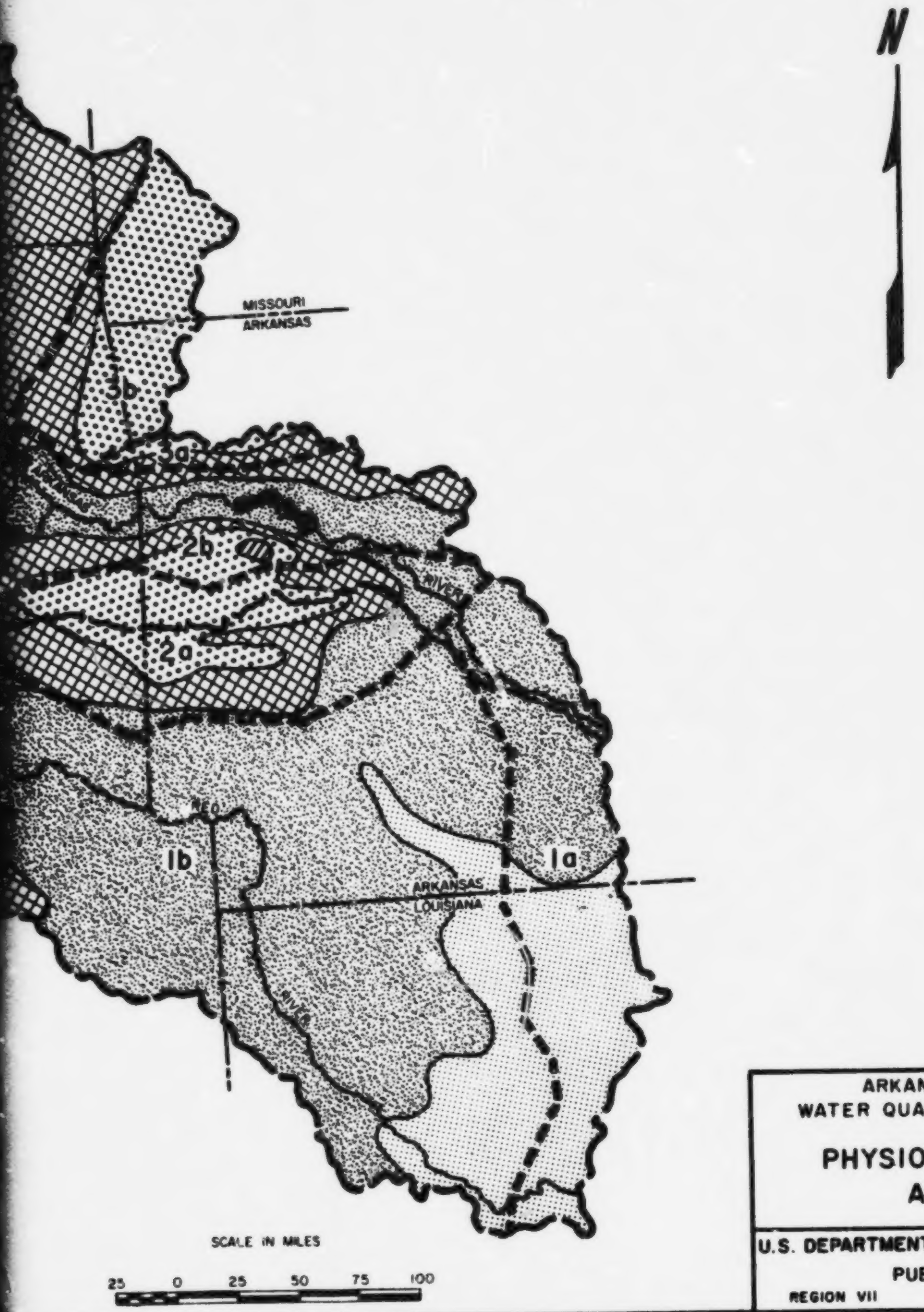
B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MISSOURI
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RIVER
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RED
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ARKANSAS
LOUISIANA
RIVER
SCALE IN MILES
25
0
25
50
75
100

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

PHYSIOGRAPHIC PROVINCES AND ELEVATIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

3 C

FIGURE 1-2

Severe rainstorms lasting several days are characteristic in the southeastern half of the Arkansas-Red River basins. Localized floods in the central and western sections result from infrequent but intense rainstorms of short duration.

The southwestern and central plains region of the United States are well known for wide fluctuations in rainfall. Both floods and extended droughts are common. Three times during the past 70 years (1892-94, 1934-36, and 1952-56), droughts have been so severe that extensive crop damage and serious water shortages have resulted.

High wind velocities and high evaporation rates are associated with the dry climate of most of the Great Plains and central lowlands. Prevailing winds are from the south. The central plains region experiences frequent periods of strong, turbulent winds in the storm winds of tornadic character and proportions.

Hydrology

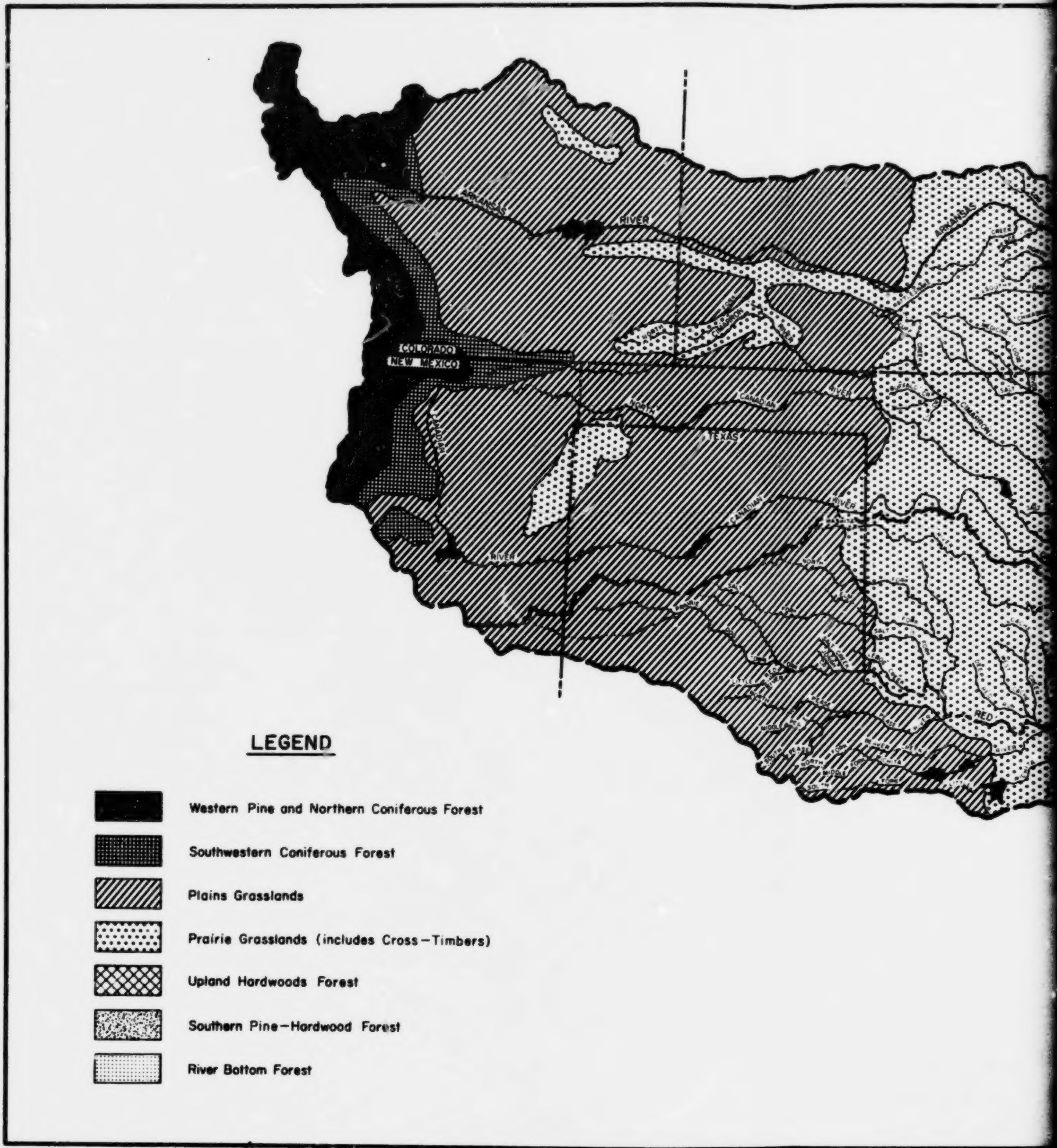
Average annual precipitation varies widely in the Arkansas-Red River basins--ranging from 32 inches on the eastern slopes of the Rocky Mountains in Colorado and New Mexico, to 12 inches along the western edge of the Great Plains, to 55 inches near the mouth of the Red River. 2/ In that portion of the Arkansas-Red River basins east of Oklahoma, the isohyets generally run east and west. In the remainder of the basins, isohyets are generally oriented north and south with a fairly constant spacing until reaching the eastern edge of the Rocky Mountains where rainfall increases sharply with elevation. (See Figure I-5.)

Geographic differences of the basins are reflected by a wide variation of the seasonal distribution of precipitation. In the eastern part of the basins, high or low rainfall can be observed in almost any month of the year. In the middle basin or Great Plains area, maximum rainfall is experienced around May or June while the minimum precipitation is generally in the winter months. A summary of precipitation records is shown in Table I-1.

Ground Water

Ground water has played an important role in supplying water requirements in the Arkansas-Red River basins. Meinzer 3/ shows that the basins lie in five ground water provinces.

The Southern Rocky Mountain province of central Colorado is underlain for the most part by crystalline rocks. Ground water in this area is generally taken from shallow wells near the streams.


COLORADO
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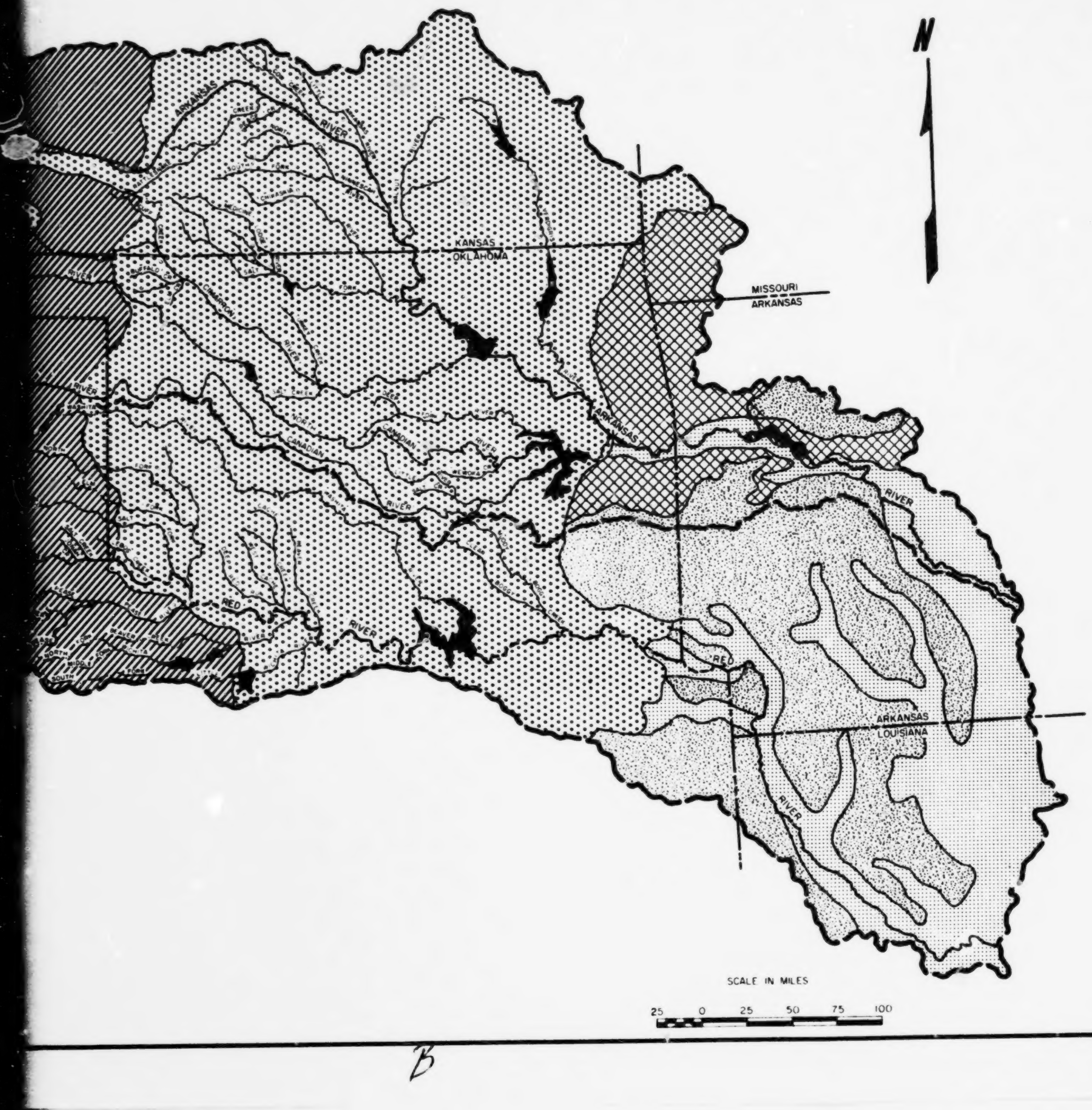
NORTH FORK
CIMARRON
RIVER
CANADIAN
RIVER
NORTH
TEXAS
CANADIAN
RIVER
CIMARRON
RED
RIVER
LEGEND
Western Pine and Northern Coniferous Forest
Southwestern Coniferous Forest
Plains Grasslands
Prairie Grasslands (includes Cross–Timbers)
Upland Hardwoods Forest
Southern Pine–Hardwood Forest
River Bottom Forest

A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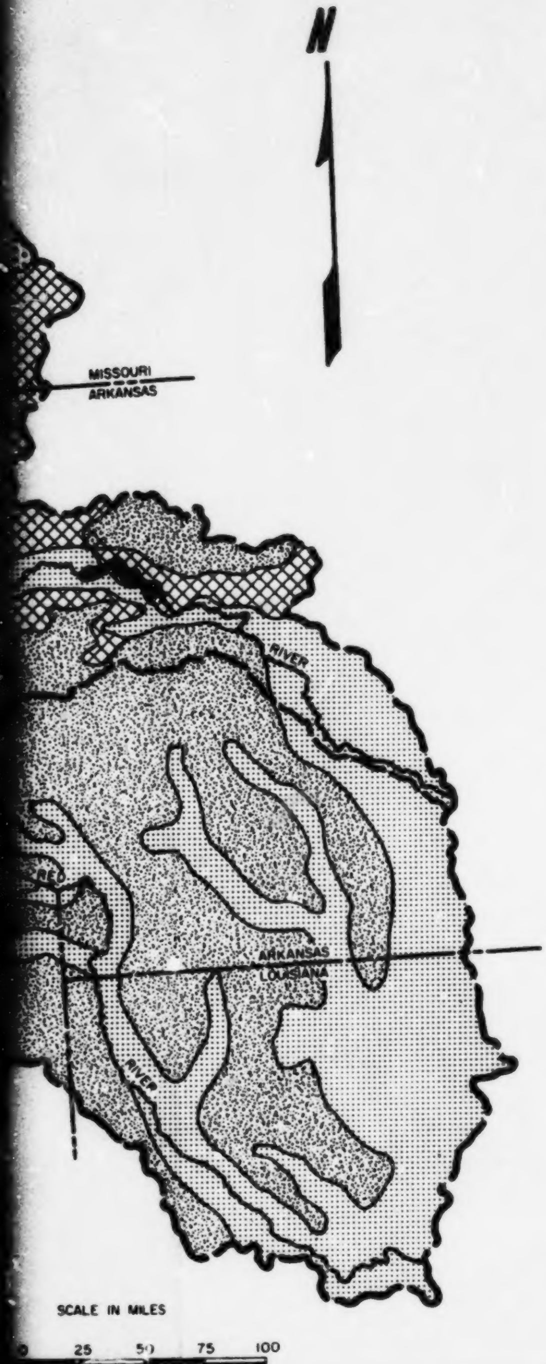
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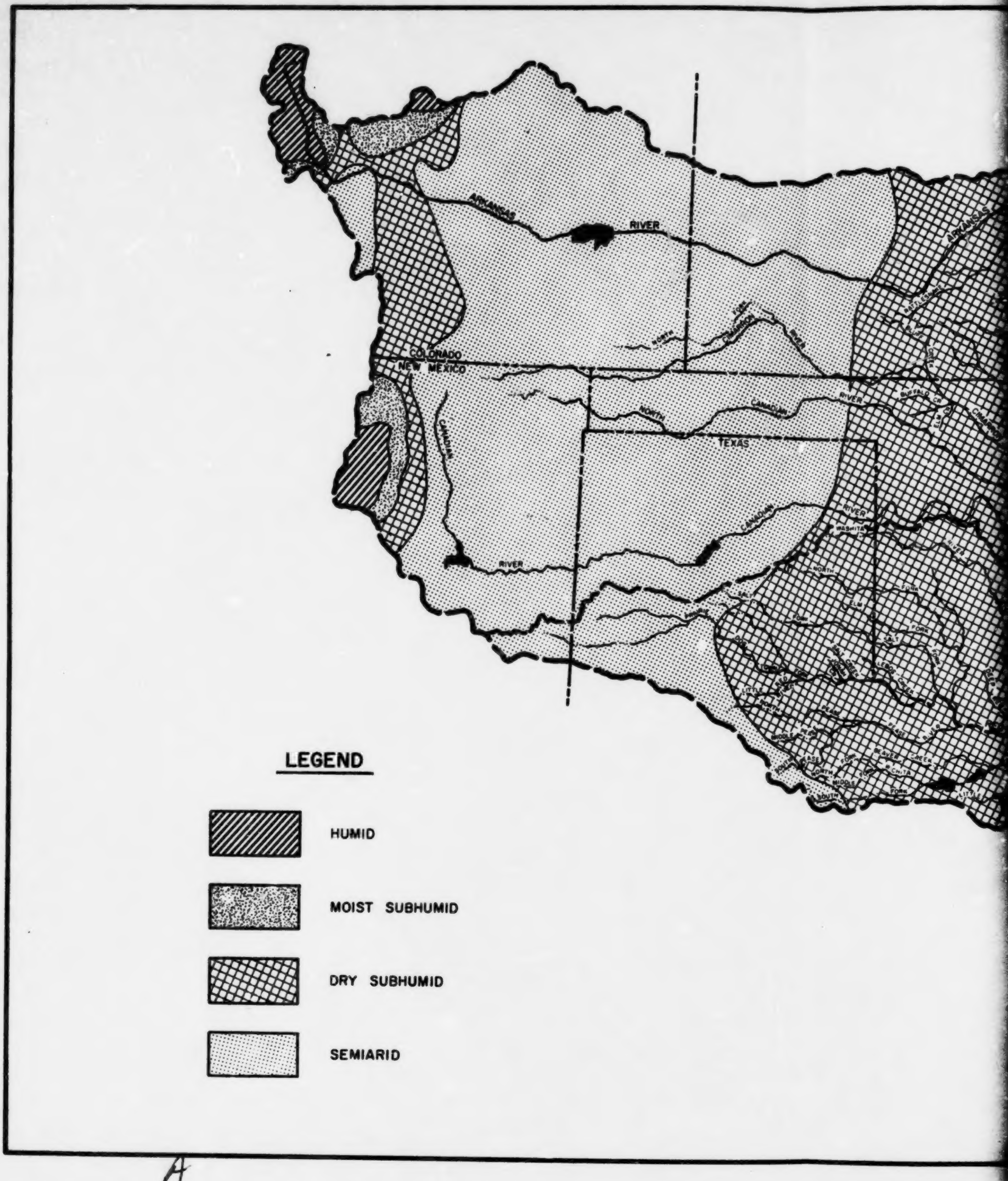
ARKANSAS – RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

NATURAL VEGETATION

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

6 C FIGURE 1 – 3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TEXAS
CANADIAN
RIVER
RIVER
WASHITA
NORTH
FORK
RED
ELM
FORK
SALT
FORK
LITTLE
NORTH
MIDDLE
SOUTH
PEASE
BEAVER
CREEK
CACHE
FORK
LITTLE
LEGEND
HUMID
MOIST SUBHUMID
DRY SUBHUMID
SEMIARID

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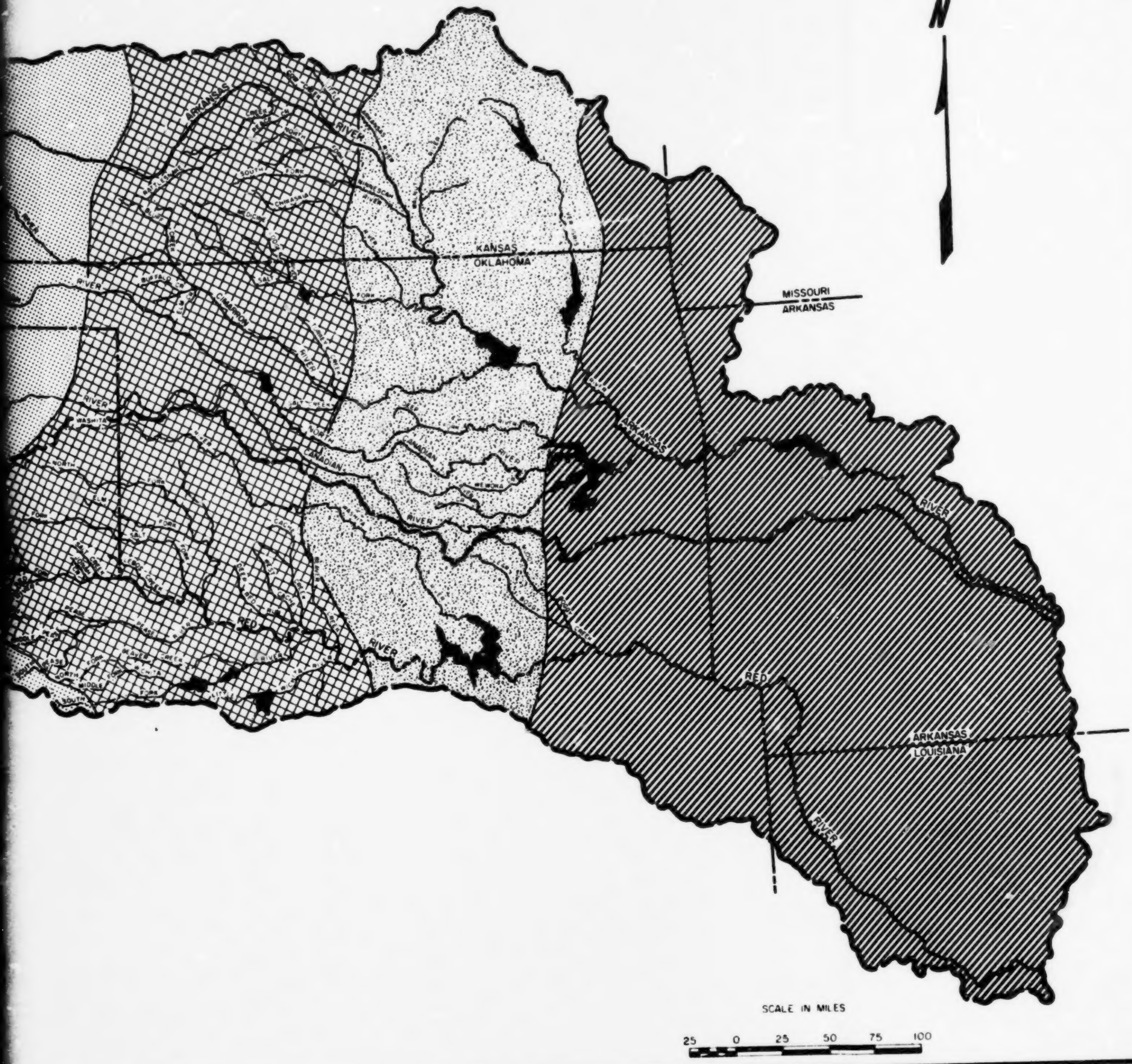
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ARKANSAS
LOUISIANA
RIVER
SCALE IN MILES
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B

MISSOURI
ARKANSAS
RIVER
RED
ARKANSAS
LOUISIANA
RIVER
SCALE IN MILES
25
50
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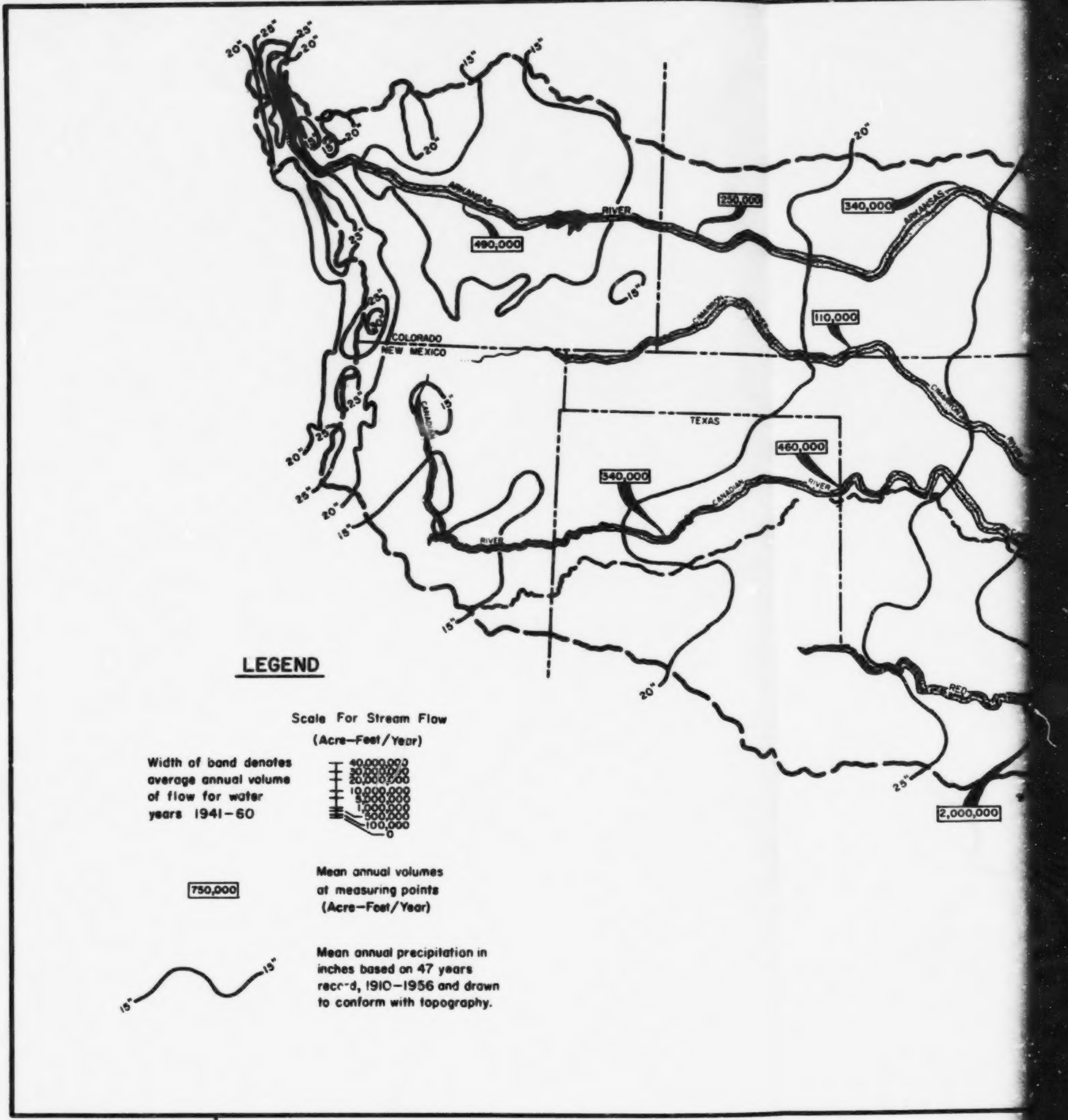
100

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

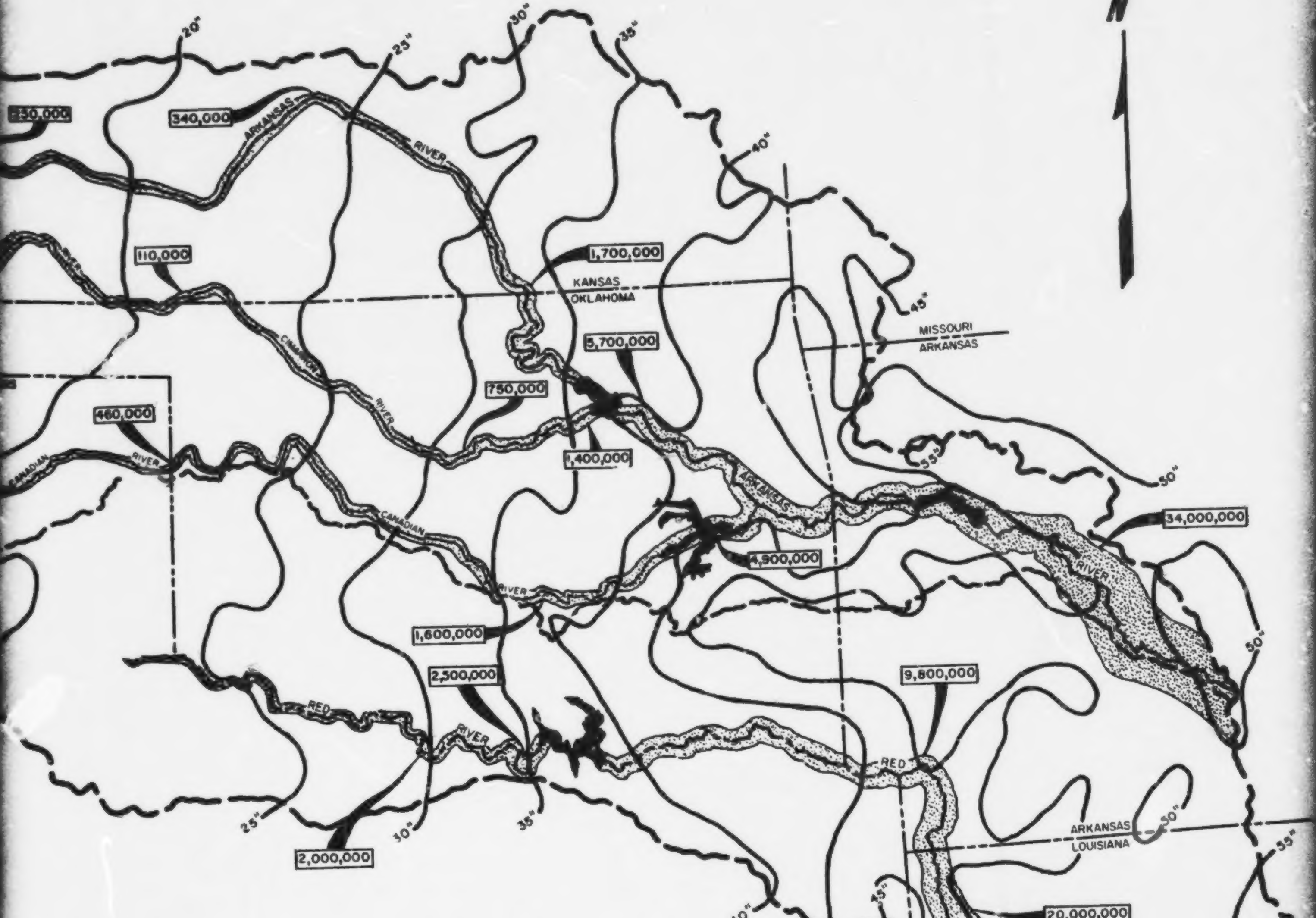
NORMAL CLIMATES

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 1-4


ARKANSAS RIVER
490,000
250,000
340,000
ARKANSAS
110,000
CIMARRON RIVER
COLORADO
NEW MEXICO
TEXAS
CANADIAN
460,000
340,000
CANADIAN RIVER
RIVER
RED
2,000,000
15"
20"
25"
LEGEND
Scale For Stream Flow
(Acre-Feet/Year)
Width of band denotes average annual volume of flow for water years 1941-60
40,000,000
30,000,000
20,000,000
10,000,000
5,000,000
1,000,000
500,000
100,000
0
750,000
Mean annual volumes at measuring points (Acre-Feet/Year)
Mean annual precipitation in inches based on 47 years record, 1910-1956 and drawn to conform with topography.

A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CIMARRON
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750,000
460,000
CANADIAN
RIVER
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55"
50"
ARKANSAS
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CANADIAN
4,900,000
RIVER
RIVER
1,600,000
50"
2,500,000
9,800,000
RED
RIVER
RED
25"
30"
35"
2,000,000
ARKANSAS
LOUISIANA
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SCALE IN MILES
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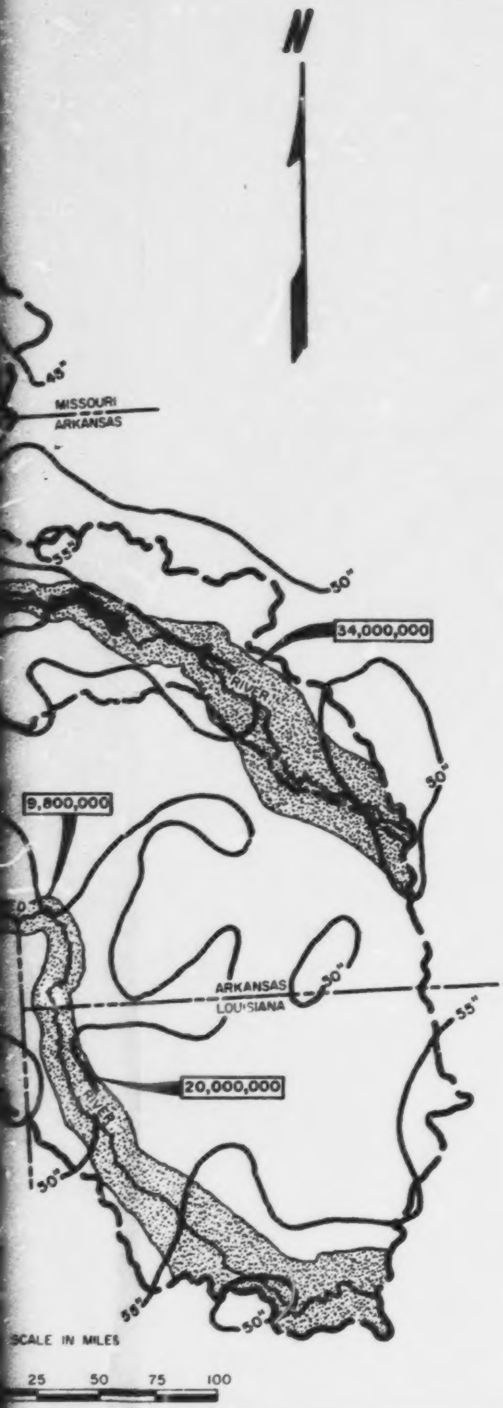
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RIVER
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SCALE IN MILES
25 50 75 100

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

RAINFALL AND STREAM FLOW

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

8 C FIGURE 1-5

Table I-1

Summary of Precipitation Records of Selected Stations in the Arkansas-Red River Basins Study Area

Weather Station	Years of Record	Annual Precipitation (Inches)				
		Mean	Maximum	Year	Minimum	Year
Pueblo, Colorado	57	11.90	23.09	1957	5.78	1934
Raton, New Mexico	54	16.11	33.76	1941	8.02	1956
Amarillo, Texas	57	20.77	39.75	1923	9.94	1956
Dodge City, Kansas	57	20.07	34.29	1944	9.97	1956
Lubbock, Texas	51	16.86	40.55	1941	8.73	1917
Colorado Springs, Colorado	57	14.59	25.07	1957	6.07	1939
Wichita, Kansas	57	30.12	50.48	1951	12.73	1956
Fort Worth, Texas	57	31.51	50.49	1957	17.91	1921
Wichita Falls, Texas	38	26.34	43.70	1941	16.36	1952
Dallas, Texas	49	34.66	55.14	1957	21.45	1956
Oklahoma City, Oklahoma	57	31.93	52.03	1908	17.27	1910
Tulsa, Oklahoma	57	37.47	62.82	1915	23.24	1956
Fort Smith, Arkansas	52	50.19	71.81	1945	19.80	1917
Texarkana, Arkansas	51	49.07	69.67	1957	28.39	1936
Shreveport, Louisiana	57	44.93	67.23	1957	26.33	1918
Little Rock, Arkansas	52	48.09	70.61	1957	31.57	1924

Source: Weather Bureau 4/

The Great Plains Pliocene-Cretaceous province of eastern Colorado and western Kansas (and a portion of the panhandle of Oklahoma) is composed of two principal aquifers--the Ogalalla Formation and the Dakota Sandstone. The Tertiary sands (Ogalalla) are satisfactory for water supply over extensive areas and yield large quantities of good water to relatively shallow sands. The Dakota Sandstone underlies nearly the entire province and gives rise to various areas of artesian flows; however, in much of the province it is too deep to be a practical source of water.

The Great Plains Pliocene-Paleozoic province forms a narrow band in central Kansas and runs into the panhandles of Oklahoma and Texas. This province is older than the Great Plains Pliocene-Cretaceous formation. The principal aquifers here are sands and gravels which, like the previously mentioned Great Plains province, yield satisfactory waters. This province is underlain by the red beds which yield little water of poor quality.

Rivers and streams in both of the Great Plains formations cut through bedrock and cannot contribute to recharge of the aquifers. Thus, the alluvium along streams in this area is an important source of water but upland water users mine this resource.

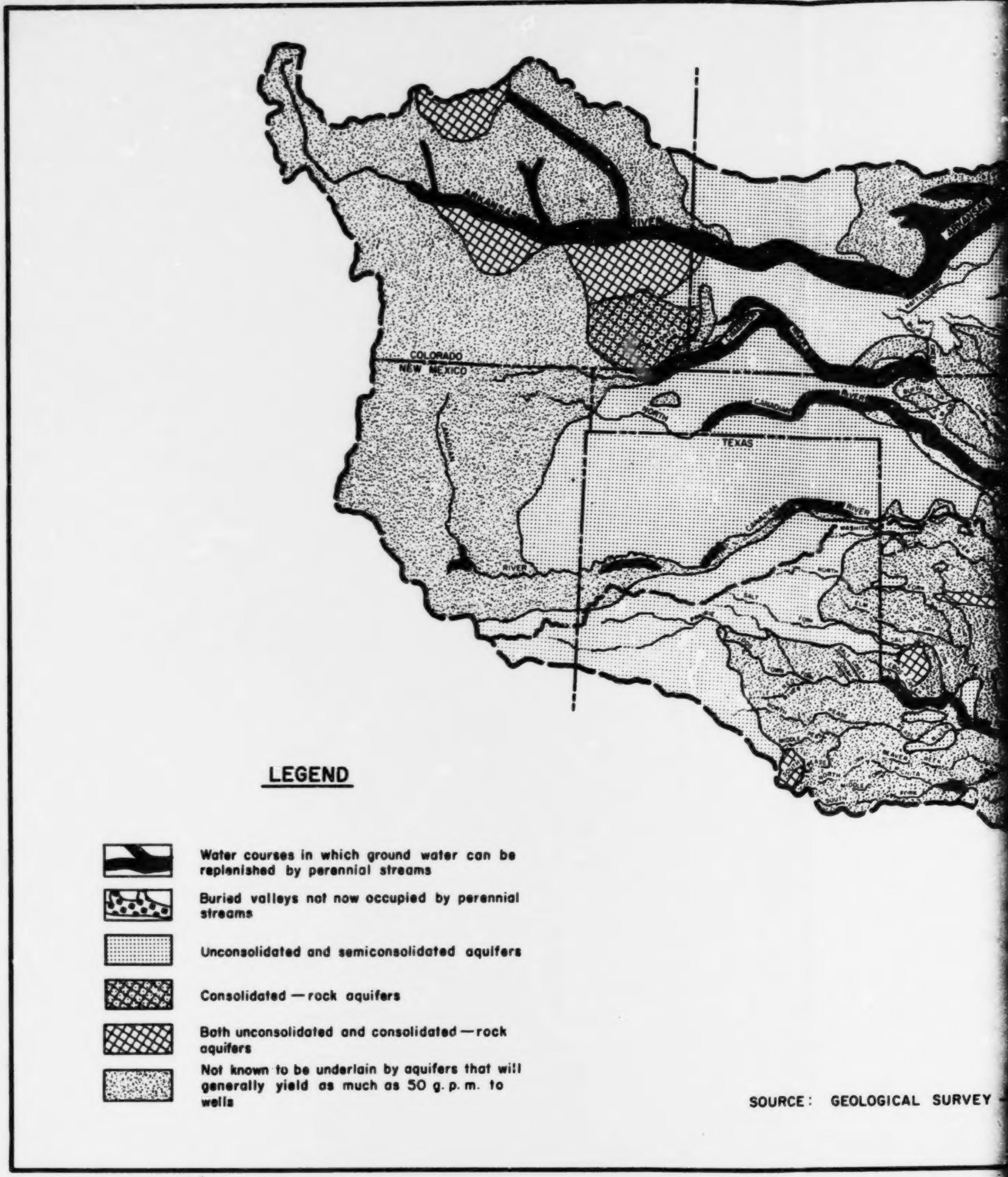
The middle portion of the basins extending into northwestern Arkansas is in the south-central Paleozoic province. Ground water conditions in this area are generally very poor with sources being Paleozoic sandstones and limestones yielding meager quantities of poor quality water. Large supplies of water are, however, obtained from the glacial outwash and other alluvial sands in many valleys.

The remaining portions of the basins are in the Atlantic Coastal province. Cretaceous, Tertiary, and Quaternary strata (chiefly sand and gravel interbedded with clay) comprise the aquifers in this area where rather large amounts of water can be obtained. Very large amounts of water can be taken from the alluvium of the Mississippi and the province includes extensive areas of artesian flow. Ground water in this province is usually of good quality; however, some waters have a high mineral content.

Figure I-6 [5] shows regions where moderate to large supplies of usable ground water can be obtained from wells. [6] The productive areas shown delineate water courses, buried valleys, and consolidated and unconsolidated aquifers.

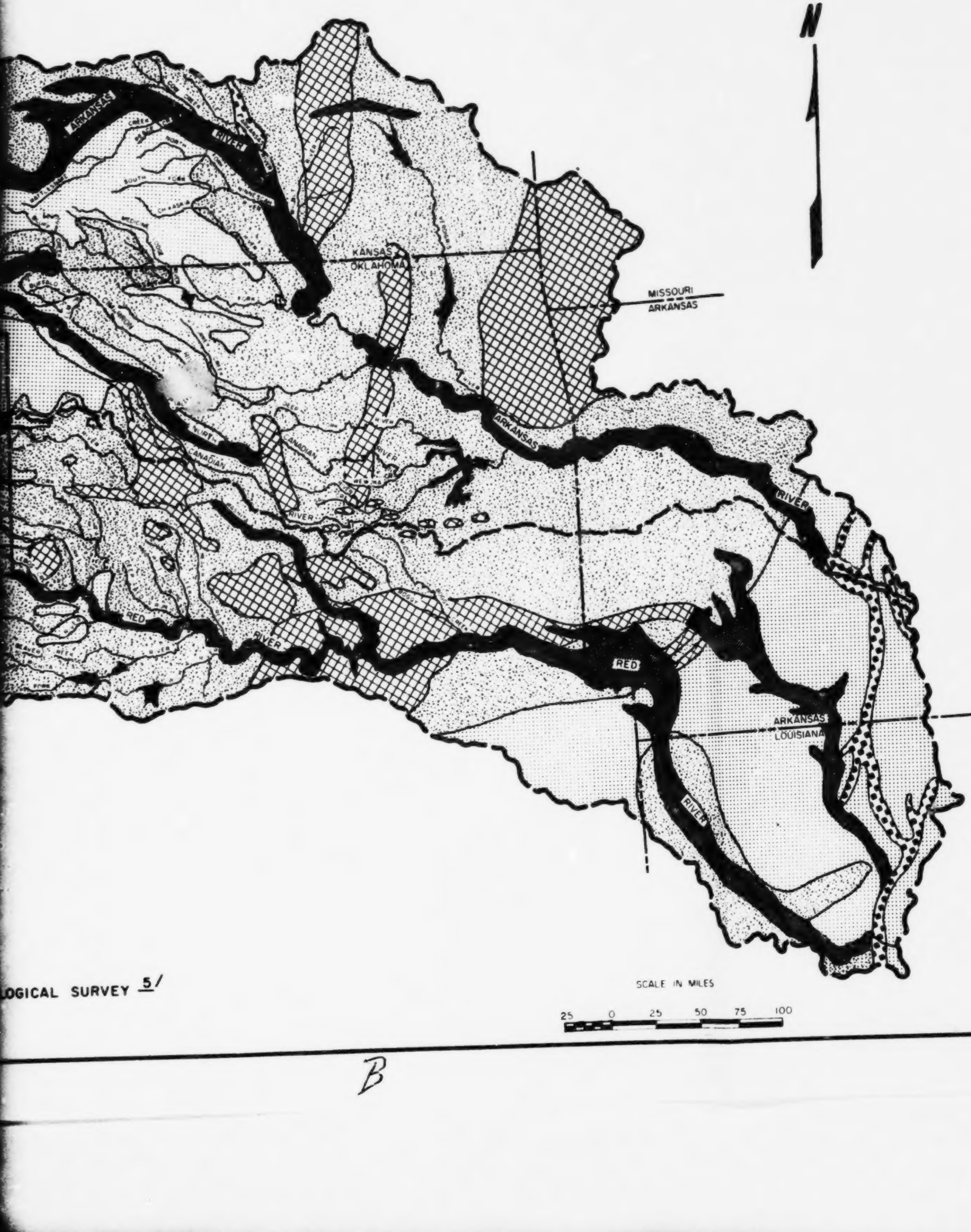
Surface Water

The total surface water resource of the two basins is large, with an average annual flow of 34 million acre-feet (46,600 cfs) in the Arkansas River at Little Rock, Arkansas, and 20 million acre-feet (27,400 cfs) in the Red River at Shreveport, Louisiana. The minimum


COLORADO
NEW MEXICO
TEXAS
ARKANSAS
RIVER
CANADIAN
RIVER
NORTH
RIVER
LEGEND
Water courses in which ground water can be replenished by perennial streams
Buried valleys not now occupied by perennial streams
Unconsolidated and semiconsolidated aquifers
Consolidated — rock aquifers
Both unconsolidated and consolidated — rock aquifers
Not known to be underlain by aquifers that will generally yield as much as 50 g. p. m. to wells

SOURCE: GEOLOGICAL SURVEY

A


N
ARKANSAS
RIVER
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OKLAHOMA
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NORTH
CANADIAN
CANADIAN
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RIVER
RED
RIVER
RED
RIVER
ARKANSAS
LOUISIANA
SCALE IN MILES
25
0
25
50
75
100

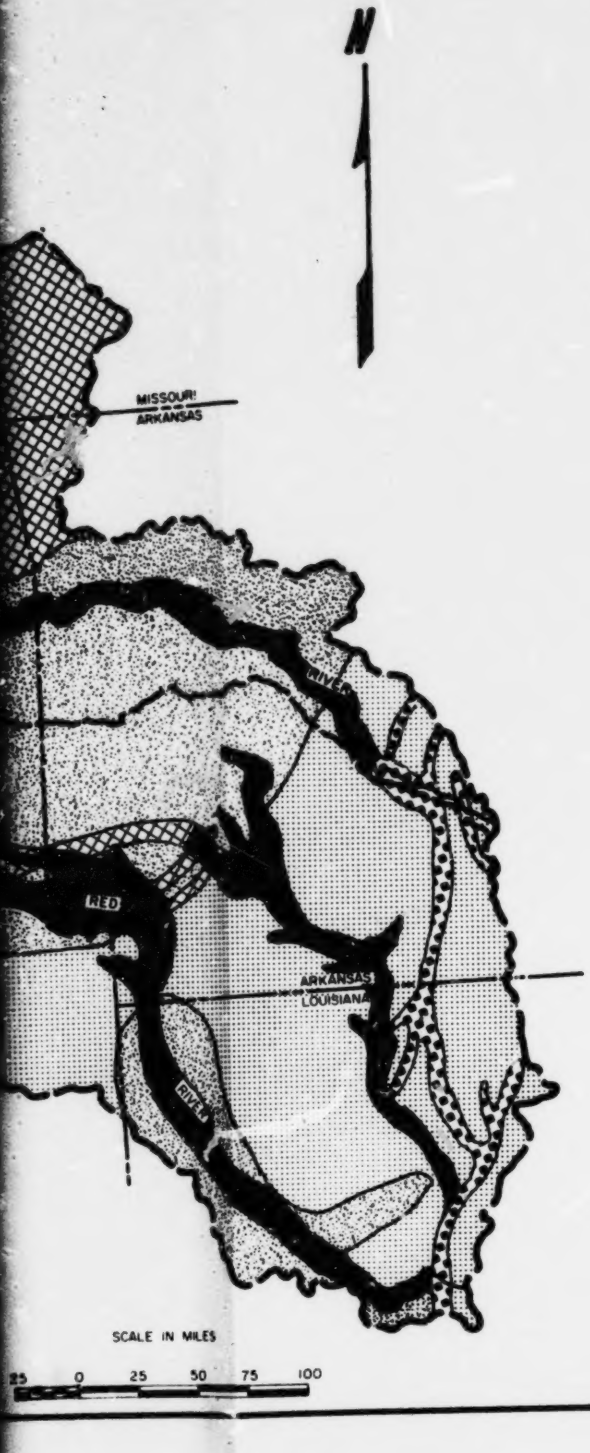
AR
WATER

U.S. DEPART

REGION VII

LOGICAL SURVEY 5/

B


N
MISSOURI
ARKANSAS
RIVER
RED
ARKANSAS
LOUISIANA
RIVER
SCALE IN MILES
25
0
25
50
75
100

ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

GROUND WATERS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE I - 6

annual flows recorded at these locations were 6.16 million acre-feet at Little Rock and 5.59 million acre-feet at Shreveport.

Streamflow characteristics differ greatly from one part of the basins to another. While in some areas the flow is closely related to rainfall or snow melt, in others it is governed more by springs. In western Oklahoma and Texas, streamflows are markedly influenced by the position of the ground water table. In this area streamflows in most of the tributaries are intermittent, while in the lower basins more evenly distributed streamflow is evident. The highest coefficients of variation of streamflow observations occur between the Colorado-New Mexico border on the west and the eastern border of Oklahoma on the east. At the eastern and western edges of this sector, the coefficient of variation is about 50 percent. The high is 72 percent, occuring in the Neosho River near Parsons, Kansas. The coefficient of variation is between 40 and 45 percent for the remainder of the Arkansas-Red River basins. 7/

The average annual runoff varies from a low of 0.10 inch in the western part of the Great Plains to a high of 20 inches in parts of Louisiana and Arkansas. 8/

Tables I-2 and I-3 show streamflow records for some locations in the Arkansas-Red River basins. In these tables a comparison of flow during the study and over the years of record can be made.

Table I-2

Streamflow Data for the Arkansas River
(cubic feet per second)

Station Number and Location	Years of Record	Average	Minimum Year	Average of 1961 and 1962 Water Years
403 - Arkansas River at Van Buren, Ark.	35	32,300	3,470	38,800
392 - Canadian River near Whitefield, Okla.	24	6,170	980	4,520
368 - Canadian River at Calvin, Okla.	23	1,970	393	1,380
367 - Little River near Sasakwa, Okla.	20	440	50	245
366 - Little River near Tecumseh, Okla.	18	163	35	104
364 - Canadian River at Bridgeport, Okla.	18	506	107	476
363 - Canadian River near Canadian, Texas	24	590	64	264
362 - Canadian River near Amarillo, Texas	24	463	92	280
361 - Canadian River at Logan, N. Mex.	34	308	23	170
390 - Deep Fork near Beggs, Okla.	24	910	114	715
388 - N. Canadian River near Wetumka, Okla.	25	771	156	525
387 - N. Canadian River near Okla. City, Okla.	16	380	56	268
762 - N. Canadian River near Okla. City, Okla.	10	149	0.4	169
283 - Verdigris River near Inola, Okla.	18	4,490	297	7,460

13

Table I-2 (Continued)

Streamflow Data for the Arkansas River
(cubic feet per second)

Station Number and Location	Years of Record	Average	Minimum Year	Average of 1961 and 1962 Water Years
770 - Arkansas River near Haskell, Okla.	37	6,740	1,280	10,000
258 - Cimarron River at Mannford, Okla.	15	1,780	432	1,880
253 - Cimarron River at Perkins, Okla.	23	1,290	235	1,410
248 - Cimarron River near Waynoka, Okla.	25	421	54	272
246 - Cimarron River near Mocane, Okla.	19	107	57	81
238 - Arkansas River at Ralston, Okla.	37	4,740	776	7,210
236 - Salt Fork of Arkansas River at Tonkawa, Okla.	27	714	97	820
235 - Salt Fork of Arkansas River near Jet, Okla.	25	404	37	360
772 - Salt Fork of Arkansas River near Ingersoll, Okla.	11	366	90	90
232 - Medicine Lodge River near Kiowa, Kansas	17	154	51	110
229 - Walnut River at Winfield, Kansas	41	766	26	1,530
227 - Arkansas River at Arkansas City, Kans.	45	1,790	366	2,600
224 - Little Arkansas River at Valley Center, Kans.	40	252	25	493
220 - Arkansas River at Great Bend, Kansas	22	453	88	257

Table I-3

Streamflow Data for the Red River
(cubic feet per second)

Station Number and Location	Years of Record	Average	Minimum Year	Average of 1961 and 1962 Water Years
529 - Red River at Index, Arkansas	26	12,700	4,840	10,600
527 - Red River at Arthur City, Texas	32	8,670	2,480	7,090
526 - Clear Boggy Creek near Caney, Okla.	19	509	54	337
522 - Red River near Colbert, Okla. (Denison Dam)	39	5,200	344	4,320
520 - Washita River near Durwood, Okla.	34	1,530	391	1,240
508 - Red River near Gainesville, Texas	26	3,170	651	2,820
507 - Red River near Terral, Okla.	24	2,570	911	2,420
704 - Little Wichita River near Henrietta, Texas	9	134	51	78
700 - Beaver Creek near Waurika, Okla.	8	154	39	74
503 - Wichita River at Wichita Falls, Texas	25	324	83	288
500 - Cache Creek near Walters, Okla.	23	181	13	163
490 - North Fork of Red River near Headrick, Okla.	27	348	32	515
483 - North Fork of Red River near Carter, Okla.	17	136	22	312

Table I-3 (Continued)

Streamflow Data for the Red River
(cubic feet per second)

Station Number and Location	Years of Record	Average	Minimum Year	Average of 1961 and 1962 Water Years
481 - Salt Fork of Red River at Mangum, Okla.	25	97	12	124
703 - Salt Fork of Red River near Wellington, Texas	8	93	46	127
478 - Red River near Brice, Texas	7	85	19	71

Study Area Definition

The Study Area

The Arkansas-Red River basins study area as detailed in Figure I-7 encompasses all of the Arkansas and Red River basins plus minor adjoining portions of the Missouri, White, Trinity, Brazos, and Sabine River basins. This area consists of a total of 327 counties in Colorado, New Mexico, Kansas, Oklahoma, Texas, Missouri, Arkansas, and Louisiana, and represents approximately 9 percent of the land area and 5 percent of the population of continental United States.

The study area included all counties partly or entirely within the Arkansas-Red River basins together with those adjoining counties which are expected to be directly affected by an improvement in the water quality of the mineral polluted streams.

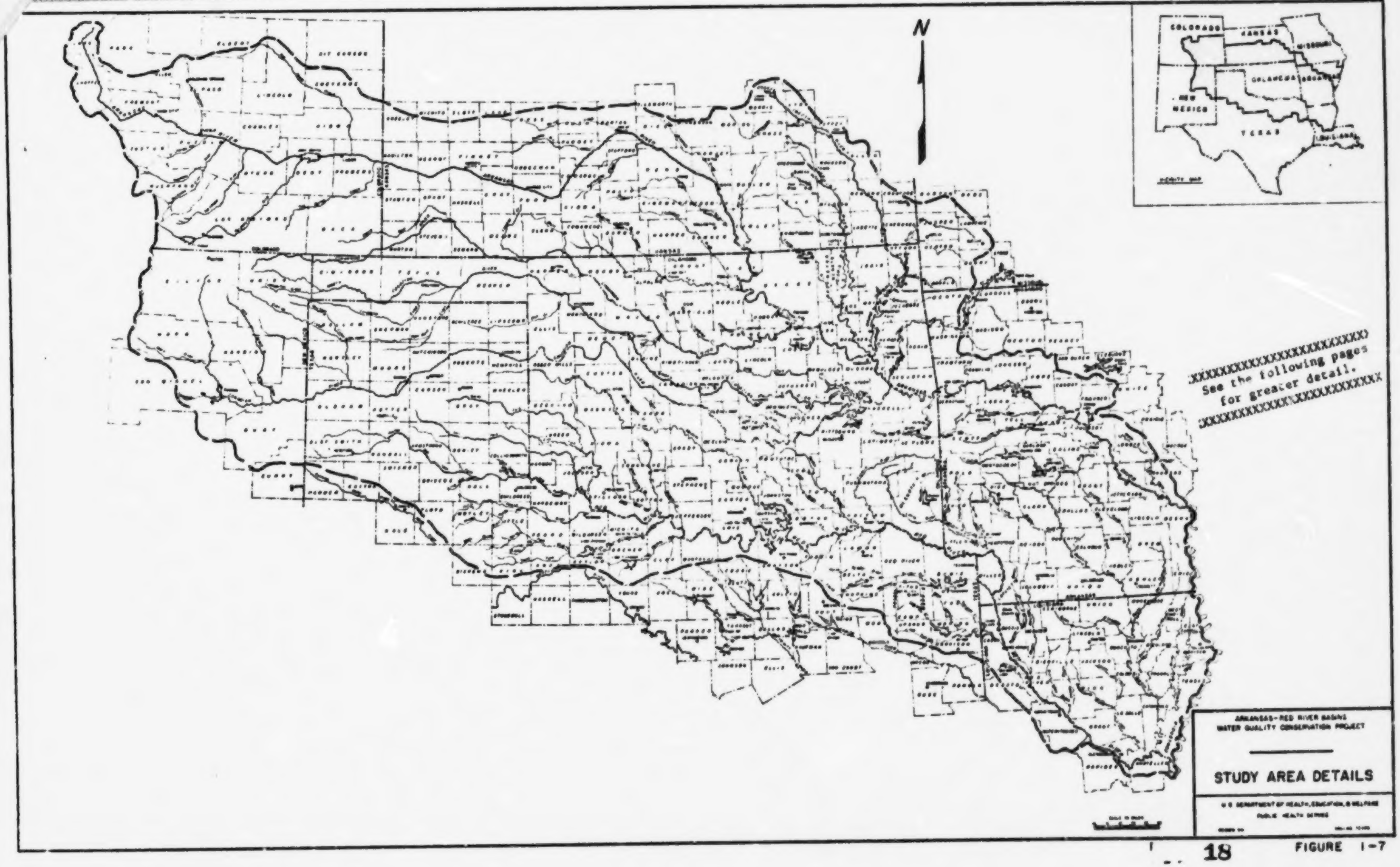
Subarea Designation

Within the study area, a wide divergence of population density and economic, mineralogical, climatological, and physiographical conditions exist which place different types of requirements on water. Descriptive statistics and data concerning population, employment, manufacturing, minerals, and agricultural are recorded by counties. The 327 counties were divided into small groups to facilitate evaluation of these data. This grouping of counties into subareas by similar characteristic provided a basis for investigation of the study area economy, water requirements, and the effects of water quality improvement.

The following criteria are considered in the selection of boundaries for subareas.

1. Population: Standard Metropolitan Statistical Area (SMSA), a central city with a population of 50,000 or more and its urbanized fringe areas, and adjacent counties expected to be influenced were grouped. Counties were also grouped into Population Center subareas. These contain at least one county with a population of 30,000 or more and adjacent influenced counties. The remaining counties were grouped to provide a minimum 1960 total population of 20,000 or more and are referred to as Rural.

2. Resources: County groupings were selected on similar mineral resources or similar land resource areas.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COLORADO
KANSAS
MISSOURI
OKLAHOMA
ARKANSAS
NEW MEXICO
TEXAS
LOUISIANA
VICINITY MAP

XXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
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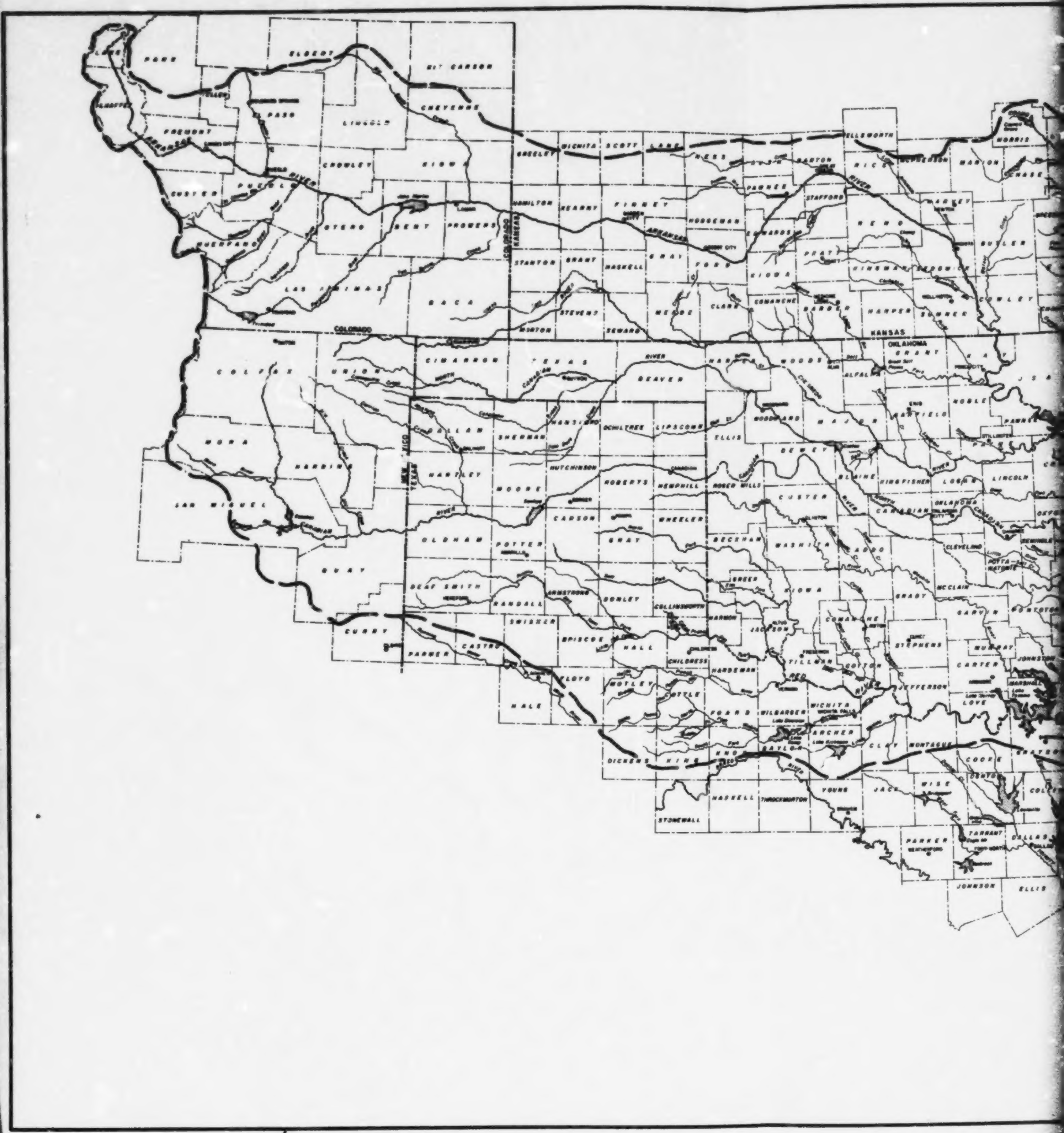
ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

STUDY AREA DETAILS

U S DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE

FIGURE 1-7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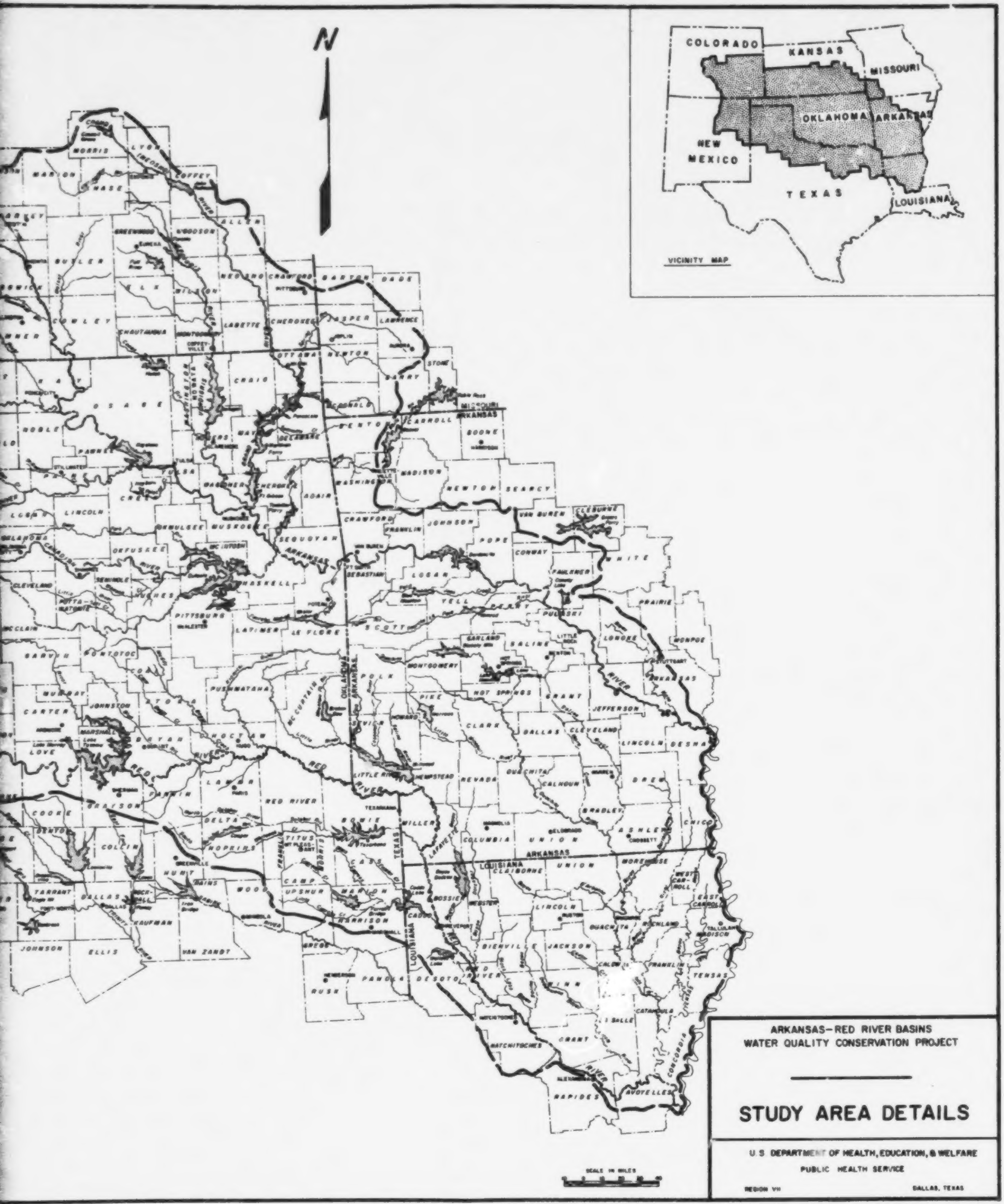
PARK
ELBERT
KIT CARSON
CHEYENNE
LINCOLN
EL PASO
TELLER
FREMONT
CROWLEY
KIOWA
CUSTER
PUEBLO
OTERO
BENT
PROWERS
HUERFANO
LAS ANIMAS
BACA
ARKANSAS
RIVER
GREELEY
WICHITA
SCOTT
LANE
NESS
BARTON
ELLSWORTH
RICE
McPHERSON
MARION
MORRIS
CHASE
HAMILTON
KEARNY
FINNEY
HODGEMAN
PAWNEE
STAFFORD
RENO
HARVEY
BUTLER
STANTON
GRANT
HASKELL
GRAY
FORD
EDWARDS
PRATT
KINGMAN
SEDGWICK
COWLEY
STEVENS
MEADE
CLARK
COMANCHE
BARBER
HARPER
SUMNER
MORTON
SEWARD
CIMARRON
TEXAS
BEAVER
WOODS
ALFALFA
KAY
NOBLE
WOODWARD
MAJOR
GARFIELD
ELLIS
DEWEY
BLAINE
KINGFISHER
LOGAN
ROGER MILLS
CANADIAN
BECKHAM
WASHITA
CADDO
CLEVELAND
POTTAWATOMIE
SEMINOLE
GREER
GRADY
McCLAIN
HARMON
JACKSON
STEPHENS
GARVIN
PONTOTOC
MURRAY
TILLMAN
COTTON
CARTER
JEFFERSON
LOVE
MARSHALL
JOHNSTON
COLFAX
UNION
MORA
HARDING
SAN MIGUEL
QUAY
CURRY
DALLAM
SHERMAN
HANSFORD
OCHILTREE
LIPSCOMB
HARTLEY
MOORE
HUTCHINSON
ROBERTS
HEMPHILL
OLDHAM
POTTER
CARSON
WHEELER
DEAF SMITH
RANDALL
ARMSTRONG
DONLEY
COLLINGSWORTH
PARMER
CASTRO
SWISHER
BRISCOE
HALL
CHILDRESS
HARDEMAN
HALE
FLOYD
MOTLEY
COTTLE
FOARD
WILBARGER
CLAY
MONTAGUE
COOKE
DICKENS
KING
KNOX
BAYLOR
ARCHER
YOUNG
JACK
WISE
DENTON
HASKELL
THROCKMORTON
STONEWALL
PARKER
TARRANT
DALLAS
JOHNSON
RED
RIVER
Wichita Falls
Fort Worth
Stillwater
Enid

A


N
COLORADO
KANSAS
MISSOURI
OKLAHOMA
ARKANSAS
NEW MEXICO
TEXAS
LOUISIANA
VICINITY MAP
SCALE IN MILES

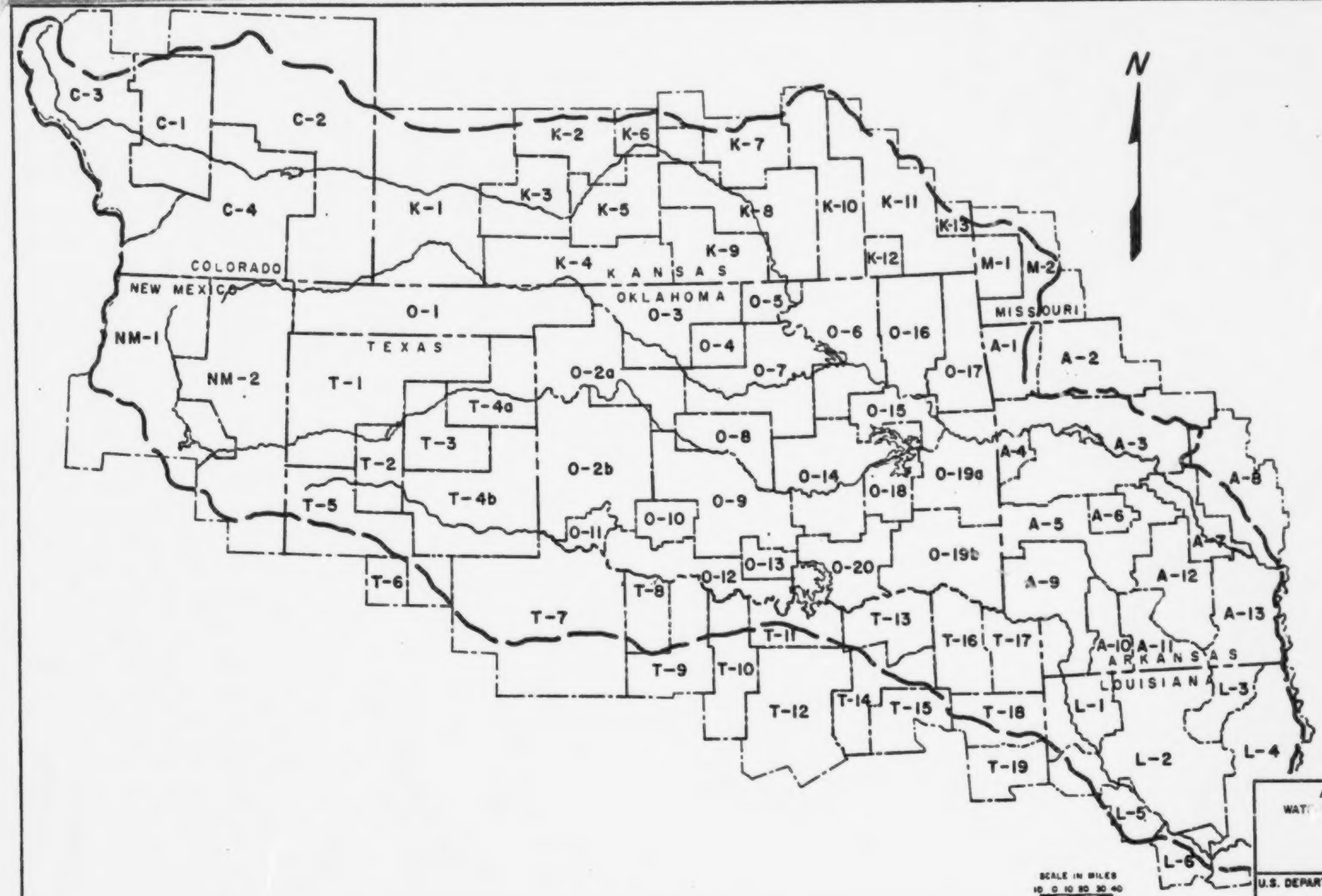
ARKANSAS—RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

STUDY AREA DETAILS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

B

FIGURE 1-7


N
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C-1
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C-4
COLORADO
NEW MEXICO
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NM-2
K-1
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K-10
K-11
K-12
K-13
KANSAS
OKLAHOMA
M-1
M-2
MISSOURI
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TEXAS
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ARKANSAS
LOUISIANA
L-1
L-2
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L-6
SCALE IN MILES
10 0 10 20 30 40

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See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXXX

ARKANSAS-RED RIVER BASINS
WAT QUALITY CONSERVATION PROJECT

SUBAREAS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 1-8

3. Political and Natural Boundaries: Subareas were defined as being within only one State, and not crossing the drainage divide between the Arkansas and Red River basins.

The 82 subareas thus developed are shown on Figure I-8 and described in Table I-4.

Subarea map designation consists of a letter and numeral. The letter refers to the State in which the subarea is located with a numbering sequence running generally from northwest to southeast. Each subarea is named for the major municipality within it.

The tabulation of geographical features includes principal streams, land areas and natural vegetation, elevation, and area. The streams listed are the major rivers in the subarea plus tributaries with drainage basins which constitute a major portion of the subarea. The land areas have a combination of physical conditions that prevail generally and that differ in recognizable and significant ways from those of adjoining areas. 1/ The natural vegetation tabulation is a listing of the generalized native vegetative zones in each subarea. 1/

The tabulation of climatological features includes for each subarea mean precipitation and temperatures detailing mean annual precipitation, mean precipitation from April through September, the growing season, mean annual temperature, and mean temperature for July and January, the warmest and coldest months, respectively.

The economic features lists principal products of agriculture, mining, and manufacturing, including agriculture products by principal farm types,2/ (products amounting to 50 percent or more of the value of all farm products sold), principal minerals of value mined in each county within the subarea from 1953 through 1960, 3/ and principal manufacturing products by Standard Industrial Classification (SIC) designation. 4/ (All manufacturing categories, except miscellaneous, with one or more plants of over 100 employees in a subarea are listed.)

Table 1-4

Subarea Descriptions

Map Designation Area		Geographical Features				Climatological Features			Economic Features		
						Precip. (Mean in.)	Temperature (Mean °F)			Principal Products	
Pop. Type Location	Counties	Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Annual Apr.-Sep.	Annual	Jan. July	Agriculture	Mining	Manufacturing
C-1 Pueblo Colo. Springs SMSA S.E. Colo.	Pueblo El Paso	Ark. R. Fountain Cr.	Rocky Mts., Brn. Plains, Plains of Up. Ark. R.; Plains Grasslands, W. Pine, & N. Coniferous Forest	4,500 to 6,000	4,554	12 9	52	29 76	Livestock Cash Grain Dairy	Clay Coal Uranium Ore Sand & Gravel Mica Feldspar	Food & kin. Print. & pub. Stone, clay, & glass Prim. metals Fab. metals Lbr. & wood Mach., except electrical Elec. mach.
C-2 Lamar Rural S.E. Colo.	Elbert Lincoln Kit Carson Cheyenne Kiowa Prowers Baca	Ark. R. Big Sandy Cr.	Brn. Plains, Plains of Up. Ark. R.; Plains Grasslands	3,500 to 6,200	14,343	15 12	54	31 78	Livestock Cash Grain	Sand & Gravel Stone	Not of Significance
C-3 Canon City Rural S.E. Colo.	Huerfano Custer Fremont Chaffee Lake Park Teller	Ark. R. S. Platte R.	Rocky Mts.; W. Pine, & N. Coniferous Forest, S.W. Coniferous Forest	5,000 to 14.400	8,047	23 11	35	18 55	Livestock	Lead & Zinc Gold Silver Copper Antimony Bismuth Cadmium Stone & Mica Shale Sand & Gravel Gypsum Coal	Stone, clay, & glass Prim. metals
C-4 Trinidad Rural S.E. Colo.	Las Animas Otero Crowley Bent	Ark. R. Purgatoire R.	Plains of Up. Ark. R.; Plains Grasslands, W. Pine, & N. Coniferous Forest, S.W. Coniferous Forest	4,500 to 7,500	8,400	15 11	50	30 76	Livestock Cash Grain	Clay Coal Sand & Gravel Gypsum Stone Petro.	Food & kin.
NM-1 Raton Rural N.E. New Mexico	Colfax Mora San Miguel	Canadian R. Mora R.	High Plains, Rocky Mts., Cimarron & Canadian Breaks; Plains Grasslands, S.W. Coniferous Forest, W. Pine, & N. Coniferous Forest	5,000 to 12,000	10,546	15 11	48	26 69	Livestock	Coal Copper Silver Beryl Clay Sand & Gravel Columbium Tantalum	Apparel & related
NM-2 Clovis Pop. Cen. N.E. New Mexico	Union Harding Quay Curry	Cimarron R. N. Canadian R. Canadian R. Ute Cr.	High Plains, Cimarron & Canadian Breaks; Plains Grasslands, Prairie Grasslands	5,000 to 6,500	10,299	17 12	53	33 73	Livestock Cash Grain	Sand & Gravel Stone Pumice	Not of Significance
K-1 Garden City Rural S.W. Kansas	Greeley Wichita Scott Lane Hamilton Kearny Finney Stanton Grant Haskell Morton Stevens Seward	Ark. R. Cimarron R.	Brn. Plains, Loessial Outwash Plains; Plains Grasslands, Prairie Grasslands	2,500 to 3,800	9,969	18 14	55	30 79	Livestock Cash Grain	Nat. Gas Petro. Sand & Gravel Nat. Gas Liq.	Petro. & coal Chem. & allied
K-2 Larned Rural S.W. Kansas	Ness Rush Pawnee	Ark. R. Walnut Cr.	Bedrock Plains; Plains Grasslands, Prairie Grasslands	1,900 to 2,600	2,540	21 16	55	30 80	Cash Grain Livestock	Petro. Nat. Gas Liq. Helium Sand & Gravel	Not of Significance
K-3 Dodge City Rural S.W. Kansas	Hodgeman Gray Ford	Ark. R.	Loessial Outwash Plains; Plains Grasslands, Prairie Grasslands	2,100 to 2,800	2,797	21 16	55	30 80	Cash Grain Livestock	Petro. Sand & Gravel Nat. Gas	Food & kin.

Table I-4 (Continued)

Subarea Descriptions

Map Designation Area Pop. Type Location	Counties	Geographical Features				Climatological Features			Economic Features		
						Precip. (Mean in.)	Temperature (Mean °F)		Principal Products		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Annual Apr.-Sep.	Annual	Jan. July	Agriculture	Mining	Manufacturing
K-4 **Medicine Lodge** Rural S.W. Kansas	Meade Clark Comanche Barber	Cimarron R. Salt Fork of Ark. R.	Red Plains; Plains Grasslands, Prairie Grasslands	2,000 to 2,800	3,879	21 16	55	30 80	Livestock Cash Grains	Petro. Nat. Gas Liq. Sand & Gravel Pumice	Stone, clay, & glass
K-5 **Pratt** Rural S.W. Kansas	Edwards Kiowa Pratt Stafford Rice	Rattlesnake Cr. Ark. R.	Great Bend Sandy Plains; Plains Grasslands, Prairie Grasslands	1,500 to 2,000	3,563	25 19	56	31 80	Cash Grains Livestock	Petro. Nat. Gas Salt Sand & Gravel Stone	Chem. & allied
K-6 **Great Bend** Pop. Cen. S. Cen. Kansas	Barton	Ark. R. Walnut Cr.	Great Bend Sandy Plains, Bedrock Plains; Prairie Grasslands	1,700 to 2,000	892	25 19	56	31 80	Cash Grain Livestock	Petro. Nat. Gas Clay Sand & Gravel	Not of significance
K-7 **Newton** Rural S. Cen. Kansas	Ellsworth McPherson Marion Harvey	Smoky Hill R. Little Ark. R. Cottonwood R.	Great Bend Sandy Plains, Bedrock Plains; Prairie Grasslands	1,200 to 1,800	3,117	29 22	57	32 81	Cash Grain Livestock Dairy	Salt Nat. Gas Petro. Sand & Gravel Stone	Petro. & coal Food & kin. Mach., except electrical Trans. equip.
K-8 **Wichita** **SMSA** S. Cen. Kansas	Cowley Butler Sedgwick Reno	Walnut R. Ninnescah R. Ark. R.	Great Bend Sandy Plains, Bluestem Hills; Prairie Grasslands	1,200 to 1,800	4,803	29 22	57	32 81	Cash Grain Livestock Dairy	Petro. Stone Nat. Gas Sand & Gravel Nat. Gas Liq.	Food & kin. Petro. & coal Stone, clay, & glass Fab. metals Print. & pub. Chem. & allied Mach., except electrical Trans. equip. Inst. & related Paper & allied
K-9 **Wellington** Rural S. Cen. Kansas	Sumner Harper Kingman	Ninnescah R. Chikaskia R.	Great Bend Sandy Plains; Prairie Grasslands	1,100 to 1,600	2,845	29 22	57	32 81	Cash Grain Livestock	Petro. Nat. Gas Sand & Gravel Stone	Not of significance
K-10 **Eureka** Rural S.E. Kansas	Chatauqua Elk Greenwood Chase Morris	Cottonwood R. Grand (Neosho) R. Fall R. Verdigris R.	Bluestem Hills, Sandstone Hills; Prairie Grasslands	900 to 1,500	3,927	34 24	57	32 81	Livestock Cash Grain	Petro. Stone Nat. Gas Sand & Gravel	Not of significance
K-11 **Emporia** Rural S.E. Kansas	Lyon Coffey Woodson Allen Wilson Neosho Labette Cherokee	Verdigris R. Grand (Neosho) R.	Claypan Prairies; Prairie Grasslands	800 to 1,600	4,930	38 27	58	33 80	Livestock Cash Grain Dairy	Coal Petro. Sand & Gravel Stone Nat. Gas Cement Zinc & Lead	Print. & pub. Stone, clay, & glass Petro. & coal Food & kin. Apparel & related
K-12 **Coffeyville** Pop. Cen. S.E. Kansas	Montgomery	Verdigris R.	Sandstone Hills; Prairie Grasslands	800 to 1,600	644	38 27	58	33 80	Cash Grain Livestock	Petro. Cement Clay Stone Nat. Gas	Food & kin. Apparel & related Chem. & allied Petro. & coal Stone, clay, & glass Prim. metals Mach., except electrical Trans. equip.
K-13 **Pittsburg** Pop. Cen. S.E. Kansas	Crawford	Grand (Neosho) R.	Claypan Prairies; Prairie Grasslands	900 to 1,100	605	38 27	58	33 80	Cash Grain Livestock	Coal Petro. Clay Stone Nat. Gas	Food & kin. Apparel & related Stone, clay, & glass Mach., except electrical Trans. equip.

Table I-4 (Continued)

Subarea Descriptions

Map Designation Area		Geographical Features				Climatological Features			Economic Features		
Pop. Type Location	Counties	Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Precip. (Mean in.) Annual Apr.-Sep.	Temperature (Mean °F) Annual	Temperature (Mean °F) Jan. July	Principal Products Agriculture	Principal Products Mining	Principal Products Manufacturing
0-1 Guymon Rural Okla. Panhandle	Cimarron Texas Beaver Harper	Cimarron R. N. Canadian R.	High Plains, Red Plains; Plains Grasslands	1,600 to 5,000	6,715	19 14	57	35 80	Cash Grain Livestock	Nat. Gas Nat. Gas Liq. Petro. Sand & Gravel	Not of Significance
0-2a Woodward Rural N.W. Okla.	Ellis Blaine Dewey Woodward	N. Canadian R. Wolf Cr. Canadian R.	Red Plains, Red Prairies; Prairie Grasslands	1,200 to 2,500	4,342	24 17	60	37 83	Cash Grain Livestock Dairy	Petro. Nat. Gas Sand & Gravel Betonite Gypsum	Stone, clay, & glass
0-2b Clinton Rural W. Cen. Okla.	Roger Mills Custer Beckham Washita Harmon Greer Kiowa	Washita R. N. Fk. Red R.	Red Plains, Wichita Mts,; Prairie Grasslands	1,300 to 2,600	6,231	24 16	61	39 83	Livestock Cotton	Petro. Nat. Gas Nat. Gas Liq. Salt Clays Sand & Gravel	Food & kin.
0-3 Alva Rural N.W. Okla.	Woods Alfalfa Grant Major	Salt Fk. of Ark. R. Cimarron R.	Red Plains, Red Prairies; Prairie Grasslands	1,000 to 2,000	4,028	25 18	60	37 84	Cash Grain Livestock	Petro. Nat. Gas Nat. Gas Liq. Salt Sand & Gravel	Not of Significance
0-4 Enid Pop. Cen. N. Cen. Okla.	Garfield	Turkey Cr. Skeleton Cr.	Red Prairies; Prairie Grasslands	1,000 to 1,400	1,054	28 19	61	38 84	Cash Grain Livestock	Petro. Nat. Gas Liq. Nat. Gas	Food & kin. Print. & pub. Petro. & coal Prim. metals Mach., except electrical
0-5 Ponca City Pop. Cen. N. Cen. Okla.	Kay	Ark. R. Salt Fk. Chikaskia R.	Red Prairies, Bluestem Hills; Prairie Grasslands	800 to 1,200	944	31 22	60	36 83	Cash Grain Livestock	Petro. Nat. Gas Liq. Nat. Gas	Petro. & coal Prim. metals Mach., except electrical Apparel & related
0-6 Tulsa SMSA N.E. Okla.	Osage Creek Washington Tulsa	Ark. R. Caney R. Polecat Cr.	Bluestem Hills, Cross Timbers, Claypan Prairies; Prairie Grasslands	600 to 1,400	4,262	37 24	61	37 82	Livestock Dairy	Petro. Nat. Gas Liq. Nat. Gas Clay Sand & Gravel	Apparel & related Petro. & coal Prim. metals Mach., except electrical Food & kin. Paper & allied Print. & pub. Chem. & allied Stone, clay, & glass Fab. metals Elec. mach. Trans. equip.
0-7 Stillwater Pop. Cen. N. Cen. Okla.	Noble Pawnee Kingfisher Logan Payne Lincoln	Ark. R. Cimarron R.	Red Prairies, Cross Timbers; Prairie Grasslands	700 to 1,400	4,641	31 21	61	38 83	Livestock Cash Grain Dairy	Petro. Nat. Gas Liq. Nat. Gas Sand & Gravel	Furn. & fix. Petro. & coal
0-8 Oklahoma City SMSA Cen. Okla.	Canadian Oklahoma Cleveland	N. Canadian R. Canadian R.	Red Prairies. Cross Timbers; Prairie Grasslands	900 to 1,600	2,141	32 21	61	37 82	Livestock Cash Grain Dairy	Petro. Nat. Gas Liq. Nat. Gas Sand & Gravel	Food & kin. Apparel & related Furn. & fix. Paper & allied Print. & pub. Stone, clay, & glass Fab. metals Mach., except electrical Elec. mach. Trans. equip.
0-9 Duncan Pop. Cen. S. Cen. Okla.	McClain Caddo Grady Garvin Stephens Murray	Canadian R. Washita R.	Red Plains. Cross Timbers. Red Prairies. Grand Prairie; Prairie Grasslands	700 to 1,800	5,061	34 22	63	41 83	Livestock Cash Grain Dairy Cotton	Petro. Nat. Gas Liq. Nat. Gas Sand & Gravel Gypsum	Petro. & coal Food & kin. Mach. electrical

Table I-4 (Continued)

Subarea Descriptions

Map Designation Area Pop. Type Location	Counties	Geographical Features				Climatological Features			Economic Features		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Precip. (Mean in.) Annual Apr.-Sep.	Temperature (Mean °F) Annual	Temperature (Mean °F) Jan. July	Agriculture	Principal Products Mining	Manufacturing
0-10 Lawton SMSA S.W. Okla.	Comanche	Cache Cr. W. Cache Cr. Beaver Cr.	Red Plains Wichita Mts., Red Prairie; Prairie Grasslands	1,000 to 2,500	1,088	30 19	63	41 84	Livestock	Petro. Nat. Gas Sand & Gravel	Food & kin. Trans. equip.
0-11 Altus Pop. Cen. S.W. Okla.	Jackson	Salt Fk. Prairie Dog Town Fk. & N. Fk. of Red R.	Red Plains; Prairie Grasslands	1,200 to 2,200	780	24 16	63	41 85	Cotton Livestock	Petro. Nat. Gas Sand & Gravel	Not of Significance
0-12 Frederick Rural S.W. Okla.	Tillman Cotton Jefferson Love	Red R. Beaver Cr.	Red Plains, Red Prairies, Cross Timbers, Grand Prairie, Coastal Plains; Prairie Grasslands	600 to 1,400	2,733	31 19	64	42 85	Livestock Cash Grain Cotton	Petro. Nat. Gas Sand & Gravel	Leather
0-13 Ardmore Pop. Cen. S. Cen. Okla.	Carter	Washita R.	Cross Timbers, Grand Prairie; Prairie Grasslands	700 to 1,400	829	37 22	64	43 84	Livestock	Petro. Nat. Gas Liq. Nat. Gas	Food & kin. Petro. & coal
0-14 Shawnee Pop. Cen. E. Cen. Okla.	Coal Pontotoc Pottawatomie Seminole Okfuskee McIntosh Hughes	N. Canadian R. Canadian R. Muddy & Clear Boggy Crs.	Cross Timbers, Claypan Prairies, Grand Prairie; Prairie Grasslands	500 to 1,300	4,834	40 24	62	40 83	Livestock Dairy	Petro. Nat. Gas Liq. Nat. Gas Coal Cement Sand & Gravel Clays	Apparel & related Stone, clay, & glass Food & kin. Elec. mach. Trans. equip. Lbr. & wood
0-15 Muskogee Pop. Cen. E. Cen. Okla.	Okmulgee Muskogee	Ark. R. Deep Fk. R.	Cross Timbers, Claypan Prairies; Prairie Grasslands	400 to 1,100	1,520	41 24	62	40 83	Livestock Cotton Dairy	Petro. Nat. Gas Coal Sand & Gravel	Petro. & coal Prim. metals Stone, clay, & glass Food & kin. Paper & allied Rubber & plas. Fab. metals
0-16 Claremore Rural N.E. Okla.	Nowata Craig Rogers Mayes Wagoner	Verdigris R. Grand (Neosho) R.	Claypan Prairies, Bluestem Hills; Prairie Grasslands	500 to 1,000	3,314	40 25	60	37 82	Livestock Dairy Cash Grain	Petro. Nat. Gas Coal Sand & Gravel	Textile mill Leather Paper & allied Chem. & allied
0-17 Miami Rural N.E. Okla.	Ottawa Delaware Cherokee Adair	Grand (Neosho) R. Illinois R.	Claypan Prairies, Ozark; Upland Hardwoods Forest	500 to 1,200	2,532	43 28	60	39 81	Livestock Dairy Cash Grain Poultry	Petro. Zinc Lead Sand & Gravel	Petro. & coal Food & kin.
0-18 McAlester Pop. Cen. E. Cen. Okla.	Pittsburg	Canadian R.	Ouachita Mts., Claypan Prairies; Prairie Grasslands	500 to 1,500	1,359	42 25	62	41 83	Livestock	Coal Nat. Gas Clay	Food & kin. Apparel & related
0-19a Poteau Rural E. Cen. Okla.	Sequoyah Haskell Latimer LeFlore	Ark. R. Poteau R. Fouche Maline R.	Ozarks, Ouachita Mts., Ark. Valley; Upland Hardwood Forest, River Bottom Forest	400 to 2,700	3,629	44 24	62	40 82	Livestock	Coal Nat. Gas Sand & Gravel	Food & kin.
0-19b Hugo Rural S.E. Okla.	Pushmataha Choctaw McCurtain	Red R. Kiamichi R. Little R. Mountain Fk. R.	Ouachita Mts., Coastal Plains, Grand Prairie, Alluvial Plains; S. Pine-Hardwood Forest, Prairie Grasslands	300 to 1,900	4,061	47 24	63	44 82	Livestock	Sand & Gravel Petro.	Apparel & related Lbr. & wood
0-20 Durant Rural S. Cen. Okla.	Johnston Atoka Marshall Bryan	Red R. Washita R. Clear & Muddy Boggy Crs. Blue R.	Grand Prairie, Coastal Plains, Arbuckle Mts., Ouachita Mts.; Prairie Grasslands	400 to 1,200	2,879	39 22	64	43 83	Livestock	Petro. Nat. Gas Liq. Nat. Gas Sand & Gravel	Apparel & related

Table I-4 (Continued)

Subarea Descriptions

Map Designation Area Pop. Type Location	Counties	Geographical Features				Climatological Features			Economic Features		
						Precip. (Mean in.)	Temperature (Mean °F)			Principal Products	
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Annual Apr.-Sep.	Annual	Jan. July	Agriculture	Mining	Manufacturing
T-1 Dalhart Rural N.W. Texas Panhandle	Oldham Hartley Dallam Sherman Moore Hansford Ochiltree	Cold Water & Palo Duro Crs. Mustang Cr. Canadian R.	High Plains, Cimarron & Canadian Breaks; Plains Grasslands, Prairie Grasslands	2,600 to 4,600	8,087	20 14	56	34 78	Cash Grain Livestock	Nat. Gas Petro. Sand & Gravel	Chem. & allied Petro. & coal Prim. metals
T-2 Amarillo SMSA Cen. Texas Panhandle	Potter Randall	Canadian R. Prairie Dog Town Fk. of Red R.	High Plains, Cimarron & Canadian Breaks; Plains Grasslands	3,000 to 3,830	1,812	20 15	57	35 78	Cash Grain Livestock	Sand & Gravel Nat. Gas	Food & kin. Print. & pub. Petro. & coal Prim. metals
T-3 Pampa Borger Pop. Cen. Cen. Texas Panhandle	Hutchinson Carson Gray	Canadian R. N. Fk. of Red R.	High Plains, Cimarron & Canadian Breaks; Plains Grasslands	2,500 to 3,500	2,720	21 15	57	35 78	Cash Grain Livestock	Petro. Nat. Gas	Chem. & allied Petro. & coal Mach., except electrical
T-4a Canadian Rural N.E. Texas Panhandle	Lipscomb Roberts Hemphill	Canadian R. Wolf Cr. Washita R.	Red Plains, Cimarron & Canadian Breaks; Plains Grasslands, Prairie Grasslands	2,200 to 3,200	2,735	21 14	59	36 81	Livestock Cash Grain	Petro. Nat. Gas	Not of Significance
T-4b Childress Rural S.E. Texas Panhandle	Wheeler Armstrong Donley Collingsworth Briscoe Hall Childress	North, Salt, & Prairie Dog Town Fks. of Red R.	Red Plains; Plains Grasslands	1,600 to 3,500	6,108	22 15	61	39 82	Cotton Livestock	Nat. Gas Petro. Stone Sand & Gravel	Chem. & allied
T-5 Hereford Rural S.W. Texas Panhandle	Deaf Smith Parmer Castro Swisher Floyd	Running Water Cr. Prairie Dog Town Fk. of Red R.	High Plains; Plains Grasslands	2,400 to 4,200	5,123	20 14	58	37 78	Cash Grain Cotton Livestock	Not of Significance	Not of Significance
T-6 Plainview Pop. Cen. S. Cen. Texas Panhandle	Hale	White R.	High Plains; Plains Grasslands	3,200 to 3,600	979	22 16	60	41 78	Cotton Cash Grain	Petro. Clay	Not of Significance
T-7 Vernon Rural N.W. Cen. S.E. of Texas Panhandle	Motley Cottle Hardeman Wilbarger Foard Dickens King Knox Baylor Stonewall Haskell Throckmorton	Pease R. Wichita R. Brazos R.	Red Plains; Plains Grasslands	1,000 to 2,400	10,540	24 15	62	43 85	Cotton Livestock Cash Grain	Petro. Nat. Gas Nat. Gas Liq. Sand & Gravel	Stone, clay, & glass Apparel & related
T-8 Wichita Falls SMSA N. Texas	Wichita	Wichita R. Red R.	Red Plains; Plains Grasslands, Prairie Grasslands	900 to 1,200	612	27 16	63	41 84	Livestock Cash Grain	Petro. Nat. Gas Liq. Sand & Gravel Stone Nat. Gas	Food & kin. Apparel & related Print. & pub. Petro. & coal Mach., except electrical
T-9 Graham Rural N. Texas	Archer Clay Jack Young	Little Wichita R. W. Fk. of Trinity R. Denton Cr. Brazos R.	Red Prairies; Plains Grasslands, Prairie Grasslands	800 to 1,400	3,850	28 17	64	44 84	Livestock	Petro. Nat. Gas Liq. Nat. Gas Sand & Gravel	Not of Significance
T-10 Weatherford Rural N. Cen. Texas	Montague Wise Parker	W. Fk. of Trinity Denton Cr. Brazos R.	Red Prairies, Grand Prairie; Prairie Grasslands	600 to 1,400	2,750	31 18	63	43 83	Livestock Dairy	Petro. Nat. Gas Nat. Gas Liq. Stone Sand & Gravel	Furn. & fix. Stone, clay, & glass

Table I-4 (Continued)

Subarea Descriptions

Map Designation Area Pop. Type Location	Counties	Geographical Features				Climatological Features			Economic Features		
						Precip. (Mean in.)	Temperature (Mean °F)		Principal Products		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Annual Apr.-Sep.	Annual	Jan. July	Agriculture	Mining	Manufacturing
T-11 Sherman Pop. Cen. N. Texas	Cooke Grayson	Red R. E. & Elm Fks. of Trinity R.	Coastal Plain, Grand Prairie, Blackland Prairies; Prairie Grasslands	500 to 1,100	1,829	37 22	65	43 84	Livestock Cash Grain Dairy	Petro. Nat. Gas Liq. Nat. Gas Stone Sand & Gravel	Leather Mach., except electrical Food & kin. Apparel & related Lbr. & wood Textile mill Paper & allied Stone, clay, & glass
T-12 Dallas - Ft. Worth SMSA N. Cen. Texas	Denton Collin Tarrant Dallas Johnson Ellis	Denton Cr. E., W., & Elm Fks. of Trinity R.	Coastal Plain, Grand Prairie, Blackland Prairies; Prairie Grasslands	300 to 1,000	5,291	34 19	65	45 84	Cotton Livestock Dairy Cash Grain	Cement Sand & Gravel Stone Clay Lime	Food & kin. Textile mill Apparel & related Lbr. & wood Furn. & fix. Paper & allied Print. & pub. Rubber & plas. Stone, clay, & glass Fab. metals Mach., except electrical Inst. & related Chem. & allied Petro. & coal Prim. metals Elec. mach. Trans. equip.
T-13 Paris Pop. Cen. N.E. Texas	Fannin Lamar Delta	Red R. N. & S. Sulphur R.	Coastal Plain, Blackland Prairies, Alluvial Plains; Prairie Grasslands	400 to 700	2,088	40 22	64	44 83	Cotton Livestock	Sand & Gravel	Textile mill Lbr. & wood Prim. metals Mach., except electrical Trans. equip. Food & kin. Fab. metals Elec. mach. Apparel & related
T-14 Greenville Pop. Cen. N.E. Texas	Hopkins Hunt Rockwall Kaufman	S. Sulphur R. Whiteoak Cr. Sabine R. E. Fk. of Trinity	Blackland Prairies, Coastal Plain; Prairie Grasslands, S. Pine-Hardwood Forest	300 to 700	2,666	40 24	65	46 83	Cotton Livestock Dairy	Petro. Nat. Gas Liq. Clay	Apparel & related Fab. metals Food & kin. Elec. mach. Trans. equip Prim. metals
T-15 Mineola Rural N.E. Texas	Wood Rains Van Zandt	Sabine R.	Blackland Prairies, Coastal Plain; Prairie Grasslands, S. Pine-Hardwood Forest	250 to 600	1,813	40 22	65	46 83	Livestock Cotton	Petro. Nat. Gas Liq. Nat. Gas Lignite Clay	Chem. & allied
T-16 Mt. Pleasant Rural N.E. Texas	Red River Franklin Titus Morris Camp	Red R. Sulphur R. Whiteoak Cr.	Coastal Plain, Blackland Prairie; Prairie Grasslands, S. Pine-Hardwood Forest	250 to 600	2,198	45 21	65	46 83	Livestock Cotton	Petro. Iron Ore Sand & Gravel	Petro. & coal Prim. metals Lbr. & wood
T-17 Texarkana Pop. Cen. N.E. Texas	Bowie Cass	Red R. Sulphur R. Fraizier & Black Cypress Crs.	Coastal Plain; S. Pine-Hardwood Forest, River Bottom Forest	200 to 500	1,886	45 23	65	45 84	Livestock	Petro. Nat. Gas Liq. Iron Ore Nat. Gas	Food & kin. Lbr. & wood Print. & pub. Stone, clay, & glass Trans. equip.
T-18 Marshall Pop. Cen. N.E. Texas	Marion Upshur Gregg Harrison	Sabine R. Little Cypress Cr.	Coastal Plain; S. Pine-Hardwood Forest	200 to 600	2,165	45 21	65	47 83	Livestock Cotton Dairy	Petro. Nat. Gas Liq. Nat. Gas Lignite Iron Ore	Apparel & related Lbr. & wood Print. & pub. Stone, clay, & glass Fab. metals Mach., except electrical Trans. equip. Chem. & allied Prim. metals
T-19 Henderson Pop. Cen. E. Texas	Rusk Panola	Sabine R.	Coastal Plain; S. Pine-Hardwood Forest	200 to 750	1,824	44 21	67	50 83	Livestock Cotton	Petro. Nat. Gas Liq. Nat. Gas Clays Lignite	Stone, clay, & glass

Table I-4 (Continued)

Subarea Descriptions

Map Designation Area Pop. Type Location	Counties	Geographical Features				Climatological Features			Economic Features		
		Principal Stream(s)	Land Areas & Natural Vegetation	Elev. Above MSL	Area (Square Miles)	Precip. (Mean in.) Annual Apr.-Sep.	Temperature (Mean °F) Annual	Temperature (Mean °F) Jan. July	Principal Products Agriculture	Principal Products Mining	Principal Products Manufacturing
M-1 Joplin Pop. Cen. S.W. Missouri	Jasper Newton	Spring R.	Ozark, Claypan Prairie; Upland Hardwood Forest, Prairie Grasslands	1,000 to 1,400	1,25[illegible]	44 28	58	35 78	Dairy Livestock Cash Grain	Sand & Gravel Stone	Food & kin. Apparel & related Lbr. & wood Print. & pub. Chem. & allied Petro. & coal Leather Stone, clay, & glass Prim. metals Fab. metals Elec. mach. Trans. equip.
M-2 Aurora Rural S.W. Missouri	Barton Dade Lawrence Stone Barry McDonald	Spring R. White R.	Ozark, Claypan Prairie; Upland Hardwood Forest, Prairie Grasslands	1,000 to 1,500	3,527	45 28	57	34 78	Dairy Livestock Cash Grain	Stone Coal Sand & Gravel	Mach., except electrical Food & kin. Apparel & related Print. & pub. Leather Fab. metals
A-1 Fayetteville Pop. Cen. N.W. Ark.	Benton Washington	Illinois R. White R. Spavinaw Cr.	Ozark, Ouachita Mts.; Upland Hardwood Forest	1,000 to 1,500	1,831	47 27	60	38 78	Poultry Dairy Livestock	Stone Sand & Gravel Nat. Gas	Food & kin. Textile mill Apparel & related Lbr. & wood Prim. metals
A-2 Harrison Rural N.W. Ark.	Carroll Boone Madison Newton Searcy	White R.	Ozark, Ouachita Mts.; Upland Hardwood Forest	1,000 to 2,500	3,604	43 24	59	26 76	Livestock Dairy Poultry	Sand & Gravel Clay Manganese	Food & kin. Apparel & related Furn. & fix. Lbr. & wood
A-3 Van Buren Rural N.W. Cen. Ark.	Crawford Franklin Johnson Pope Logan Scott Yell Perry Conway Van Buren Cleburne Faulkner	Ark. R. Petit Jean Cr. Fourche La Fave R.	Ark. Valley, Ouachita Mts.; Upland Hardwood Forest, S. Pine-Hardwood Forest, River Bottom Forest	500 to 2,800	8,532	52 26	62	42 81	Livestock Poultry Dairy Cotton Cash Grain	Sand & Gravel Stone Nat. Gas Coal Clay	Food & kin. Leather Rubber & plas. Furn. & fix. Textile mill Apparel & related Trans. equip.
A-4 Ft. Smith SMSA W. Ark.	Sebastian	Ark. R.	Ouachita Mts., Ark. Valley, Claypan Prairies; Upland Hardwood Forest, River Bottom Forest	500 to 1,000	531	40 23	62	40 82	Dairy Livestock	Coal Nat. Gas Stone Clay	Food & kin. Furn. & fix. Paper & allied Print. & pub. Stone, clay, & glass Prim. metals Fab. metals Elec. mach.
A-5 Benton Rural Cen. & W. Cen. Ark.	Polk Montgomery Hot Spring Clark Saline	Ouachita R. Caddo R. Little Mo. R.	Ouachita Mts., Coastal Plains; S. Pine-Hardwood Forest	100 to 1,500	4,868	52 24	63	43 82	Livestock Poultry Dairy	Bauxite Clay Sand & Gravel Lime Talc Stone Manganese Slate Barite Gem Stones	Apparel & related Textile mill Stone, clay, & glass Prim. metals Lbr. & wood Chem. & allied
A-6 Hot Springs Pop. Cen. Cen. Ark.	Garland	Ouachita R.	Ouachita Mts.; S. Pine-Hardwood Forest	500 to 1,500	738	56 28	63	44 82	Livestock	Oilstones Grinding pebbles Sand & Gravel Gem Stones Whetstones	Lbr. & wood
A-7 Little Rock SMSA Cen. Ark.	Pulaski Jefferson	Ark. R.	Ouachita Mts., Alluvial Plains, Coastal Plains; S. Pine-Hardwood Forest	100 to 750	1,684	48 21	62	42 81	Cotton	Stone Sand & Gravel Bauxite Clays	Food & kin. Textile mill Apparel & related Lbr. & wood Furn. & fix. Paper & allied Print. & pub. Stone, clay, & glass Elec. mach. Inst. & related Fab. metals Trans. equip. Prim. metals
A-8 Stuttgart Pop. Cen. E. Cen. Ark.	White Lonoke Arkansas Monroe Prairie	Bayou Meto L. Red R.	Loess Hills & Terraces, Alluvial Plains, Ouachita Mts.; River Bottom Forest, Upland Hardwood Forest	100 to 750	4,109	52 23	63	43 82	Cotton Cash Grain Livestock	Stone Clay	Food & kin. Leather Mach., except electrical Apparel & related

Table I-4 (Continued)

Subarea Descriptions

Map Designation Area Pop. Type Location	Counties	Geographical Features: Principal Stream(s)	Geographical Features: Land Areas & Natural Vegetation	Geographical Features: Elev. Above MSL	Geographical Features: Area (Square Miles)	Climatological Features: Precip. (Mean in.) Annual Apr.-Sep.	Climatological Features: Temperature (Mean °F) Annual	Climatological Features: Temperature (Mean °F) Jan. July	Economic Features: Principal Products: Agriculture	Economic Features: Principal Products: Mining	Economic Features: Principal Products: Manufacturing
A-9 Texarkana Pop. Cen. S.W. Ark.	Sevier Howard Pike Little R. Hempstead Miller Lafayette	Red R. Little R. Cossatot R. Rolling Fk. Saline R. Little Mo. R. Bodcan Bayou	Coastal Plains, Ouachita Mts., Alluvial Plains; S. Pine-Hardwood Forest, River Bottom Forest	100 to 750	4,220	49 24	64	46 83	Livestock Cotton Poultry	Cement Sand & Gravel Gypsum Gem Stones Stone Petro. Nat. Gas Sulphur Nat. Gas Liq.	Lbr. & wood Stone, clay, & glass Apparel & related
A-10 Magnolia Rural S.W. Ark.	Nevada Columbia	Bayou Dorcheat	Coastal Plains; S. Pine-Hardwood Forest	100 to 500	1,384	49 22	65	47 82	Livestock	Petro. Sand & Gravel Nat. Gas Nat. Gas Liq.	Lbr. & wood Apparel & related
A-11 El Dorado Pop. Cen. S. Cen. Ark.	Ouachita Union	Ouachita R. Little Mo. R.	Coastal Plain; S. Pine-Hardwood Forest, River Bottom Forest	100 to 500	1,790	53 23	65	46 82	Livestock	Petro. Sand & Gravel Nat. Gas Clays Bromine Nat. Gas Liq.	Lbr. & wood Furn. & fix. Paper & allied Petro. & coal Trans. equip. Food & kin. Apparel & related Fab. metals
A-12 Warren Rural S. Cen. Ark.	Grant Dallas Cleveland Calhoun Bradley	Moro Cr. Ouachita R. Saline R.	Coastal Plains; S. Pine-Hardwood Forest, River Bottom Forest	100 to 500	3,184	54 23	64	46 82	Cotton Livestock Poultry	Sand & Gravel Petro.	Lbr. & wood
A-13 Crossett Rural S.E. Ark.	Lincoln Desha Drew Ashley Chicot	Bayou Bartholomew Ark. R. Saline R. Miss. R.	Alluvial Plains, Loess Hills & Terraces, Coastal Plains; S. Pine-Hardwood Forest, River Bottom Forest	100 to 500	3,774	53 23	64	45 82	Cotton Livestock	Sand & Gravel	Apparel & related Textile mill Trans. equip. Lbr. & wood Paper & allied Chem. & allied
L-1 Shreveport SMSA N.W. Louisiana	Caddo Bossier Webster	Red R. Bayou Dorcheat Bayou Bodcau	Coastal Plains, Alluvial Plains; S. Pine-Hardwood Forest, River Bottom Forest	100 to 250	2,571	45 21	66	48 83	Livestock Cotton	Petro. Nat. Gas Nat. Gas Liq. Sand & Gravel	Food & kin. Lbr. & wood Print. & pub. Stone, clay, & glass Fab. metals Mach., except electrical Chem. & allied Petro. & coal Leather Prim. metals Paper & allied
L-2 Ruston Rural N. Cen. Louisiana	Clairborne Union Lincoln Bienville Red R. DeSoto Jackson Winn Caldwell Grant La Salle	Red R. Bayou D'Arbonne Little R. Black Lake Bayou Saline Bayou	Coastal Plains, Alluvial Plains; S. Pine-Hardwood Forest	100 to 300	7,670	54 23	66	48 82	Livestock Cotton	Petro. Nat. Gas Nat. Gas Liq. Clay Sand & Gravel Shell	Lbr. & wood Fab. metals Paper & allied
L-3 Monroe SMSA N.E. Louisiana	Ouachita Morehouse	Ouachita R. Bartholomew Bayou Bouef R.	Coastal Plains, Alluvial Plains; River Bottom Forest	50 to 300	1,446	53 25	66	48 82	Cotton Livestock	Nat. Gas Petro. Sand & Gravel Clay	Food & kin. Apparel & related Lbr. & wood Paper & allied Print. & pub. Chem. & allied
L-4 Tallulah Pop. Cen. N. Cen. E. Louisiana	W. Carroll E. Carroll Richland Madison Franklin Tensas Catahoula Concordia Avoyelles	Tensas R. Macon Bayou Bouef R.	Loess Hills & Terraces, Alluvial Plains; River Bottom Forest	50 to 150	5,564	52 22	65	49 81	Cotton Livestock	Nat. Gas Petro. Sand & Gravel Nat. Gas Liq.	Lbr. & wood Food & kin. Mach., except electrical
L-5 Natchitoches Pop. Cen. Cen. Louisiana	Natchitoches	Red R.	Coastal Plains; Alluvial Plains; River Bottom Forest, S. Pine-Hardwood Forest	100 to 350	1,297	52 24	66	50 82	Cotton Livestock	Petro. Clay Nat. Gas	Food & kin.
L-6 Alexandria Pop. Cen. Cen. Louisiana	Rapides	Red R.	Coastal Plains, Alluvial Plains; S. Pine-Hardwood Forest, River Bottom Forest	50 to 250	1,329	57 27	67	51 81	Cotton Livestock	Sand & Gravel Petro. Clay Nat. Gas	Food & kin. Lbr. & wood Leather

Source: Arkansas-White-Red Basins Inter-Agency Committee 2/
Bureau of the Census 16/
Bureau of Mines 17/
Bureau of the Census 21/

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Study Area Economy

National growth in production of goods and services is reflected differently in all portions of the United States, because of the tendency toward regional production specialization. The larger the region, however, the more nearly it parallels overall national growth. Since the Arkansas-Red River basins study area contains 5 percent of the Nation's population in 9 percent of its continental land area, an examination of historic growth trends of income, employment, population and production in the Nation and the study area provides a good indication of relative growth of the study area.

Income

The most meaningful measure of national output is gross national product (GNP). Since directly comparable figures are not available on a regional basis, estimates of per capita income for the study area were used for comparative analysis. As shown in Table I-5, per capita income for the study area has been lower than the per capita income for the United States. However, it should be noted that per capita income is increasing in the study area at a faster rate than per capita income for the Nation. Constant dollar per capita income increased 180 percent in the study area between 1930 and 1960 and 100 percent during the same time period for the United States.

Table I-5

Per Capita Personal Income for the Study Area
and the United States 1930-1960
(1960 Dollars)

Year	Study Area*	United States
1930	648	1,106
1940	692	1,257
1950	1,437	1,835
1960	1,822	2,223

*Study area per capita income estimates based on state income weighted according to proportion of population in study area for Kansas, Oklahoma, Texas, and Arkansas.

Source: Office of Business Economics 9/ and Bureau of the Census 10/

Employment

The diversity of the study area's economy is indicated by the distribution of the labor force among the several major sectors of employment. For instance, in 1960, 9 percent of a total labor force of 3,370,000 was employed in agriculture; 3 percent was employed in mining, chiefly petroleum and gas drilling; and 17 percent was employed in manufacturing, as shown in Table I-6. Based on the 1950 and 1960 trend, the significant changes in the labor force have been in the agriculture and manufacturing categories. The similarity to the national condition is manifest in these figures.

The increase in the category "All Other Employed" reflects the increasing role in government, military, and service in the study area. Although unemployment and underemployment do exist in the study area, the proportion of unemployed to total labor force is consistently smaller in the study area than in the United States. A detailed breakdown of 1960 employment for each subarea appears in Table I-7.

Table I-6

Employment in the Study Area
and the United States 1950-1960

	1950			1960		
	Study Area		U.S.	Study Area		U.S.
	Total	Percent	Percent	Total	Percent	Percent
Agriculture	599,349	19.6	11.6	307,230	9.1	7.8
Mining	114,567	3.7	1.4	89,941	2.7	1.0
Manufacturing	393,011	12.8	23.5	566,792	16.8	22.9
All Other Employment	1,846,470	60.2	58.3	2,259,605	67.1	62.9
Unemployed	112,346	3.7	5.2	143,689	4.3	5.4
Total Labor Force	3,065,743	100.0	100.0	3,367,257	100.0	100.0

Source: Bureau of the Census 11/

Population

Over 9,300,000 people reside in the study area, largely in metropolitan areas varying in size from Dallas with a 1960 population of over a million to cities such as Oklahoma City, Tulsa, and Fort Worth with 1960 populations of about a half million and Lawton, Oklahoma; Fort Smith, Arkansas; and Texarkana, Texas and Arkansas, with 1960 populations of less than 100,000. 12/ The population growth rate of the entire area from 1950 to 1960 has been 1 percent compounded annually. The national rate was 1.75 percent over the same period.

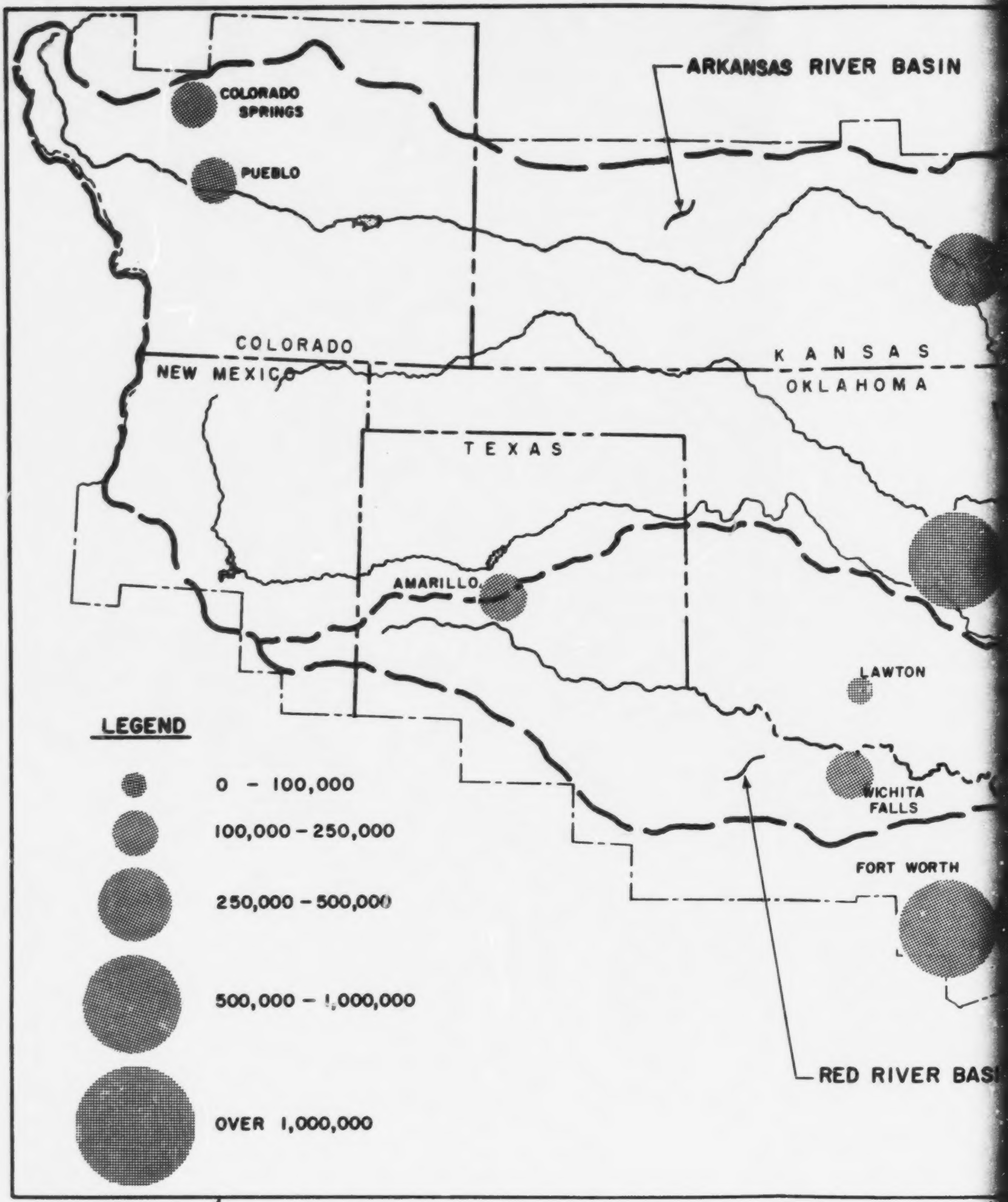
Table I-7

Study Area Employment by Subareas - 1960

Map Designation	Area	Agriculture	Forestry & Fisheries	Mining	Construction	Manufacturing	Total Basic a/	Total Service b/	Employed	Unemployed
Colorado										
C-1	Pueblo-Colo. Springs	2,351	49	140	5,306	17,271	25,117	55,988	81,105	4,300
C-2	Lamar	5,254	8	68	917	528	6,775	8,324	15,099	355
C-3	Canon City	1,423	38	1,055	1,272	1,430	5,218	10,319	15,537	862
C-4	Trinidad	2,884	8	1,048	929	1,561	6,430	10,555	16,985	828
New Mexico										
NM-1	Raton	1,450	18	160	892	779	3,299	7,278	10,577	1,120
NM-2	Clovis	2,629	9	35	1,274	755	4,702	11,207	15,909	641
Kansas										
K-1	Garden City	6,152	--	1,321	2,003	1,296	10,772	15,284	26.056	363
K-2	Larned	2,500	--	130	484	201	3,315	4,704	8,019	191
K-3	Dodge City	2,266	--	41	746	774	3,827	6,660	10,487	261
K-4	Medicine Lodge	2,067	--	370	491	421	3,349	4,348	7,697	174
K-5	Pratt	3,610	4	1,144	903	769	6,430	9,630	16,060	512
K-6	Great Bend	1,445	--	1,515	730	1,001	4,691	7,478	12,169	539
K-7	Newton	5,377	--	898	1,740	3,528	11,543	16,247	27,790	784
K-8	Wichita	7,281	35	3,168	9,424	51,320	71,228	105,304	176.532	7.977
K-9	Wellington	3,973	12	387	867	2,137	7,376	9,228	16,604	497
K-10	Eureka	3,785	4	941	756	601	6,087	6,078	12,165	458
K-11	Emporia	8,797	--	882	3,115	7,643	20,437	29,447	49,884	1,921
K-12	Coffeyville	1,063	--	392	785	3,932	6,172	9,731	15,903	884
K-13	Pittsburg	1,298	--	256	684	1,857	4,095	8,641	12,736	817
Oklahoma										
O-1	Guymon	3,444	--	788	912	429	5,573	6,439	12,012	235
O-2a	Woodward	3,830	--	459	893	820	6,002	7,591	13,593	365
O-2b	Clinton	8,929	--	357	2,470	1,329	13,085	17,615	30,700	1,145
O-3	Alva	4,413	--	185	814	500	5,912	7,510	13,422	329
O-4	Enid	1,609	--	239	1,166	2,419	5,433	12,745	18,178	560
O-5	Ponca City	1,488	--	325	924	5,822	8,559	9,933	18,492	574
O-6	Tulsa	3,679	9	12,754	10,775	34,057	61,274	110,475	171,749	7,631
O-7	Stillwater	5,885	12	2,162	3,032	3,061	14,152	24,503	38,655	1,428
O-8	Oklahoma City	4,094	9	4,394	13,618	22,519	44,634	152,194	196,828	5,981
O-9	Duncan	7,421	12	4,656	3,385	4,897	20,371	27,917	48,288	2,361
O-10	Lawton	1,051	8	114	1,796	1,153	4,122	15,611	19,733	1,025
O-11	Altus	1,312	--	43	547	365	2,267	5,111	7,378	372
O-12	Frederick	3,108	--	392	992	849	5,341	6,111	11,452	459
O-13	Ardmore	779	--	1,881	994	967	4,621	8,153	12,774	678
O-14	Shawnee	4,848	3	3,199	3,517	4,734	16,301	27,339	43,640	2,938
O-15	Muskogee	2,115	--	643	1,999	5,698	10,455	20,276	30,731	1,922
O-16	Claremore	3,838	7	1,083	2,714	3,443	11,085	13.832	24.917	1,391
O-17	Miami	2,847	18	196	1,855	3,153	8,069	11,494	19,563	1 259
O-18	McAlester	1,125	8	358	639	1,283	3,413	6,617	10,030	671
O-19a	Poteau	2,434	85	512	1,307	2,586	6,924	8,953	15,877	1.490
O-19b	Hugo	2,269	128	81	1,003	2,678	6,159	6,820	12,979	721
O-20	Durant	3,021	20	308	1,341	1,372	6,062	8,895	14,957	888
Texas										
T-1	Dalhart	2,897	9	1,300	1,126	1,990	7,322	8,942	16,264	288
T-2	Amarillo	1,523	9	847	4,948	6,014	13,341	40,568	53,909	1,666
T-3	Pampa-Borger	1,320	--	3,275	2,342	6,611	13,548	14,285	27,833	963
T-4a	Canadian	934	4	181	258	67	1,344	1,574	2,918	57
T-4b	Childress	4,706	--	206	1,081	447	6,440	8,339	14,779	579
T-5	Hereford	8,526	--	73	1,116	491	10,206	9,142	19,348	628
T-6	Plainview	3,618	--	28	907	727	5,280	7,637	12,917	453
T-7	Vernon	7,915	--	1,172	1,854	1,270	12,211	13,837	26,048	904
T-8	Wichita Falls	1,171	17	3,793	3,556	3,969	12,506	29,864	42,370	2,138
T-9	Graham	1,763	--	2,203	1,054	651	5,671	6,191	11,862	453
T-10	Weatherford	2,984	5	1,230	1,827	3,048	9,094	10,295	19,389	705
T-11	Sherman	2,805	--	1,206	2,280	6,335	12,626	20,175	32,801	1,163
T-12	Dallas-Ft. Worth	14,862	76	7,306	46,417	153,747	222,408	434,202	656,610	22,396
T-13	Paris	4,821	9	39	1,634	3,475	9,978	11,810	21,788	1,130
T-14	Greenville	5,743	--	88	2,779	5,768	14,378	18,492	32,870	1,305
T-15	Mineola	2,867	4	799	1,181	1,521	6,372	7,095	13,467	592
T-16	Mt. Pleasant	2,617	7	393	1,132	4,566	8,715	9,584	18,299	783
T-17	Texarkana	1,840	22	300	1,985	5,854	10,001	16,519	26,520	1,637
T-18	Marshall	1,940	25	2,488	3,582	9,825	17,860	30,313	48,173	2,036
T-19	Henderson	1,931	20	1,570	1,636	2,517	7,674	9,606	17,280	863
Missouri										
M-1	Joplin	2,903	--	196	2,154	9,502	14,835	22,568	37,403	1.936
M-2	Aurora	7,092	31	54	1,818	5,421	14,416	12,888	27,304	1,167
Arkansas										
A-1	Fayetteville	5,541	31	44	2,312	6,531	14,459	18,281	32,740	1,292
A-2	Harrison	4,972	80	36	1,171	3,651	9,910	7,018	16,928	622
A-3	Van Buren	8,561	368	527	4,428	11,389	25,273	24,155	49,428	3,724
A-4	Fort Smith	458	8	248	1,318	5,573	7,605	15,386	22,991	1,964
A-5	Benton	1,867	136	980	1,663	8,885	13,531	13,745	27,276	2,073
A-6	Hot Springs	385	77	64	1,141	2,276	3,943	11,424	15,367	741
A-7	Little Rock	4,454	54	240	7,946	20,066	32,760	80,488	113,248	5,101
A-8	Stuttgart	10,105	125	33	2,179	5,048	17,490	16,244	33,734	2,075
A-9	Texarkana	4,553	121	286	2,061	7,249	14,270	16,992	31,262	2,070
A-10	Magnolia	1,297	57	714	751	3,078	5,897	6,598	12.495	898
A-11	El Dorado	695	67	1,237	1,424	4,086	7,509	19,271	26,780	1,627
A-12	Warren	1,279	86	70	726	5,427	7,588	5,870	13,458	777
A-13	Crossett	7,440	173	21	1,251	5,665	14,550	11,595	26,145	1.829
Louisiana										
L-1	Shreveport	4,154	117	3,907	8,534	14,588	31,300	75,389	106,689	5,805
L-2	Ruston	4,969	532	2,044	4,324	10,893	22,762	29,154	51,916	2,903
L-3	Monroe	2,437	49	460	3,417	8,407	14,770	27,971	42,741	2,308
L-4	Tallulah	14,851	281	1,062	3,553	3,809	23,556	22,453	46,009	3,023
L-5	Natchitoches	1,594	130	37	712	926	3,399	5,903	9,302	915
L-6	Alexandria	1,716	185	104	2,393	3,491	7,889	23,756	31,645	2,193
	Grand Total	307,230	3,419	89,941	227,982	566,792	1,195,364	2,028,204	3,223,568	143,689

a/ The Total Basic category includes all commodity-producing industries (agriculture, forestry, fisheries, mining, construction, and manufacturing).
b/ The Total Service category includes all noncommodity-producing industries (wholesale and retail trade, government, and others).

Source: Bureau of the Census 11/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FORT WORTH
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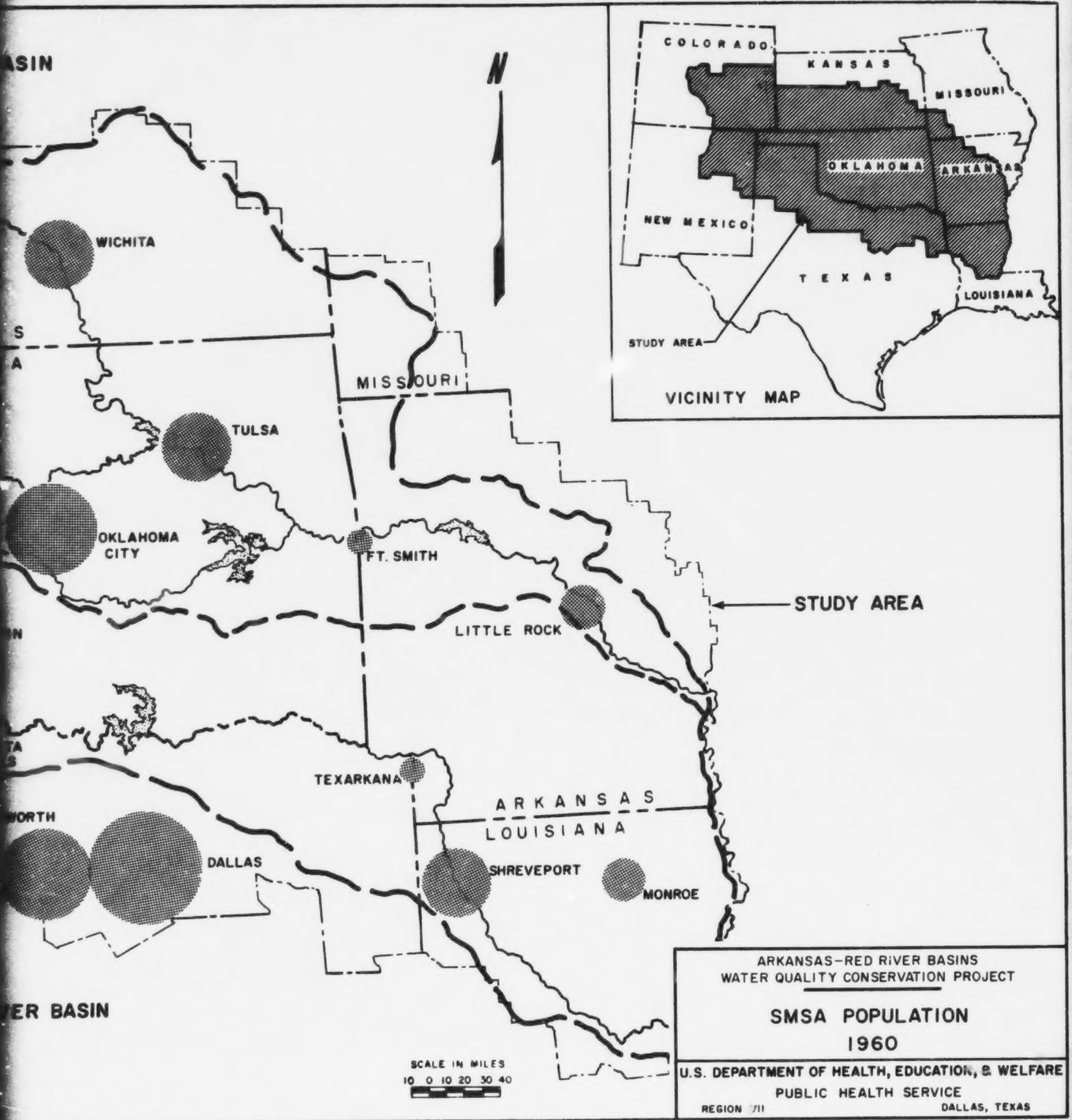
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ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

SMSA POPULATION
1960

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

B

FIGURE 1-9

The population trend in the study area reflects the national condition of rural area decline and urban area increase. This change is due to loss of employment opportunities in mechanized, large-scale agriculture and to the consequent exodus of the surplus farm labor to the cities and to other migration and social factors.

The study area lost 15 percent of its rural population from 1950 to 1960; the totals were 4,320,000 in 1950 and 3,670,000 in 1960. The urban population grew by 37 percent over the same 10-year period, from 4,120,000 to 5,660,000. 12/ The national rates for these two segments of the population were one-third of 1 percent and 30 percent, respectively, for the same period of time.

These comparisons of study area population trends with the national condition indicate that the study area possesses not only a capacity and potential for growth, but also that it compares favorably with the Nation in actual growth. This favorable comparison is particularly manifest in the metropolitan areas (SMSA's) of the region such as Dallas, Fort Worth, Oklahoma City, Tulsa, Wichita, and Shreveport, which had a population growth rate of 3.25 percent compounded annually from 1950 to 1960. The national rate in these population categories was 2.625 percent. A detailed picture of the SMSA populations in the study area and the Nation is presented in Table I-8. Figure I-9 shows the distribution of SMSA population in the study area. A breakdown of urban-rural population by subareas for 1910-1960 appears in Table I-9.

Table I-8

Study Area and U.S. Population--Total, Urban, Rural, and Standard Metropolitan Statistical Area 1910-1960 (Millions)

Population Component	1910	1920	1930	1940	1950	1960
		Study Area				
Total	6.1	7.1	8.0	8.1	8.4	9.3
Urban	1.3	1.9	2.7	3.0	4.1	5.6
Rural	4.8	5.2	5.3	5.1	4.3	3.7
SMSA	0.6	1.2	1.8	2.1	3.1	4.3
SMSA as % of Total	9.8	16.9	22.5	26.0	38.0	46.3
		United States				
Total	92.0	105.7	122.8	131.7	150.7	179.3
Urban	42.0	54.2	69.0	74.4	96.5	125.3
Rural	50.0	51.5	53.8	57.3	54.2	54.0
SMSA	35.3	47.2	62.3	68.1	85.8	111.2
SMSA as % of Total	38.4	44.7	50.7	51.7	56.9	62.0

Source: Bureau of the Census 12/

Table I-9

Study Area Population - Total, Urban, and Rural by Subareas
1910-1960

Map Designation	Area	Type a/	Component b/	1910	1920	1930	1940	1950	1960
Colorado									
C-1	Pueblo-Colorado Springs	SMSA	Total	95,544	101,665	115,608	122,895	164,711	262,449
			Urban	70,825	73,155	83,333	91,431	109,157	165,001
			Rural	24,719	28,510	32.275	31,464	55,554	97.448
C-2	Lamar	Rural	Total	37,353	54,235	56,996	43,122	46,880	40.795
			Urban	2,977	2,512	4,233	4,445	6,829	7,369
			Rural	34,376	51,723	52,763	38,677	40,051	33 426
C-3	Canon City	Rural	Total	68,513	59,990	57,300	62,827	48,430	49,084
			Urban	19,807	20,393	20,277	24,920	23,347	25.433
			Rural	48,706	39,597	37,023	37,907	25,083	23,651
C-4	Trinidad	Rural	Total	60,400	77,686	75,466	73,126	65,174	55.508
			Urban	19,116	19,616	23,340	26,989	27,226	27,048
			Rural	41,284	58,070	52,126	46,137	37,948	28 460
New Mexico									
NM-1	Raton	Rural	Total	52,001	58,332	53,125	57,609	51,994	43,302
			Urban	11,469	15,530	15,187	18,969	22,004	21,964
			Rural	40,532	42,802	37,938	38,640	29,990	21,338
NM-2	Clovis	Pop. Center	Total	37,759	38,924	42,094	43,739	47,707	52,912
			Urban	5,781	8,021	14,688	19,447	29,252	35,170
			Rural	31,978	30,903	27,406	24,292	18,455	17,742
Kansas									
K-1	Garden City	Rural	Total	33,456	38,520	54,048	43,075	61,267	69,536
			Urban	3,171	7,461	11,415	10,695	21,243	35,248
			Rural	30,285	31,059	42,633	32,380	40,024	34,288
K-2	Larned	Rural	Total	22,568	25,173	27,961	25,449	24,594	21,884
			Urban	2,911	3,139	3,532	3,533	4,447	5,001
			Rural	19,657	22,034	24,429	21,916	20,147	16,883
K-3	Dodge City	Rural	Total	17,444	22,718	31,015	25,562	27,874	28,433
			Urban	3,214	5,061	10,059	8,487	11,262	13.520
			Rural	14,230	17,657	20,956	17,075	16,612	14,913
K-4	Medicine Lodge	Rural	Total	22,345	25,572	27,070	23,088	22,065	20,885
			Urban	-----	-----	-----	-----	-----	3,072
			Rural	22,345	25,572	27,070	23,088	22,065	17,813
K-5	Pratt	Rural	Total	51,979	52,521	50,902	51,537	47,286	43,226
			Urban	3,302	7,699	9,261	11,088	12,068	12,748
			Rural	48,677	44,822	41,641	40,449	35,218	30,478
K-6	Great Bend	Pop. Center	Total	17,876	18,422	19,776	25,010	29,909	32,368
			Urban	4,622	4,460	8,549	12,763	19,246	23,647
			Rural	13,254	13,962	11,227	12,247	10,663	8,721
K-7	Newton	Rural	Total	73,580	75,891	76,579	74,670	70,140	72,970
			Urban	11,408	14,376	17,181	18,242	20,279	27,482
			Rural	62,172	61,515	59,398	56,428	49,861	45,488
K-8	Wichita	SMSA	Total	165,797	215,654	260,922	265,628	344,254	478,542
			Urban	86,151	129,915	175,883	181,103	240,541	348.902
			Rural	79,646	85,739	85,039	84,525	103,713	129,640
K-9	Wellington	Rural	Total	57,076	54,988	55,169	50,232	44,233	44,815
			Urban	12,273	9,788	13,104	13,332	13,739	15,135
			Rural	44,803	45,200	42,065	36,900	30,494	29,680
K-10	Eureka	Rural	Total	57,541	54,496	57,608	50,616	40,945	33,570
			Urban	2,545	5,463	6,596	6,678	6,680	6,719
			Rural	54,996	49,033	51,012	43,938	34,265	26,851
K-11	Emporia	Rural	Total	190,371	185,714	176,924	166,692	151,534	138,739
			Urban	57,445	67,997	68,304	66,482	69,076	70,785
			Rural	132,926	117,717	108,620	100,210	82,458	67,954
K-12	Coffeyville	Pop. Center	Total	49,474	49,645	51,411	49,729	46,487	45,007
			Urban	31,068	33,497	36,025	34,734	34,276	34,069
			Rural	18,406	16,148	15,386	14,995	12,211	10,938
K-13	Pittsburg	Pop. Center	Total	51,178	61,800	49,329	44,191	40,231	37,032
			Urban	18,151	24,438	18,145	20,125	19,341	18,678
			Rural	33,027	37,362	31,184	24,066	20,890	18,354

Table I-9 (Continued)

Map Designation	Area	Type a/	Component b/	1910	1920	1930	1940	1950	1960
Oklahoma									
0-1	Guymon	Rural	Total	40,622	39,092	38,721	28,652	32,212	31,479
			Urban	-----	-----	-----	-----	4,718	5,768
			Rural	40,622	39,092	38,721	28,652	27,484	25,711
0-2a	Woodward	Rural	Total	64,059	54,645	60,087	55,260	45,547	37,487
			Urban	2,696	3,849	5,056	8,234	9,164	10,999
			Rural	61,363	50,796	55,031	47,026	36,383	26,488
0-2b	Clinton	Rural	Total	136,128	120,791	163,853	125,638	106,530	91,587
			Urban	13,460	11,751	31,972	32,176	38,068	40,902
			Rural	122,668	109,040	131,881	93,462	68,462	50,685
0-3	Alva	Rural	Total	69,713	60,690	58,589	54,118	45,965	36,325
			Urban	3,688	3,913	5,121	7,608	9,140	6,258
			Rural	66,025	56,777	53,468	46,510	36,825	30,067
0-4	Enid	Pop. Center	Total	33,050	37,500	45,588	45,484	52,820	52,975
			Urban	13,799	16,576	26,399	28,081	36,017	38,859
			Rural	19,251	20,924	19,189	17,403	16,803	14,116
0-5	Ponca City	Pop. Center	Total	26,999	34,907	50,186	47.084	48,892	51,042
			Urban	5,787	16,758	28,968	28,528	33,022	37,414
			Rural	21,212	18,149	21,218	18,556	15,870	13,628
0-6	Tulsa	SMSA	Total	98,803	235,041	326,800	319,927	360,780	461,321
			Urban	35,422	116,327	194,235	195,873	246,229	338.940
			Rural	63,381	118,714	132,565	124,054	114,551	122,381
0-7	Stillwater	Pop. Center	Total	141,356	139,493	149,385	138,664	129.334	113,571
			Urban	20,769	31,256	41,069	44,205	52,832	55,588
			Rural	120,587	108,237	108,316	94,459	76,502	57,983
0-8	Oklahoma City	SMSA	Total	127,576	157,984	274,802	299,216	392,339	511,833
			Urban	75,802	104,036	207,952	231,523	308,340	463,919
			Rural	51,774	53,948	66,850	67,693	83,999	47,914
0-9	Duncan	Pop. Center	Total	143,194	157,728	196,872	177,969	158,812	147,853
			Urban	22,872	27,057	41,876	44,986	58,602	67,290
			Rural	120,322	130,671	154,996	132,983	100,210	80,563
0-10	Lawton	SMSA	Total	34,317	26,629	41,489	38,988	55,165	90,803
			Urban	7,788	8,930	12,121	18,055	34,757	61,697
			Rural	26,529	17,699	29,368	20,933	20,408	29,106
0-11	Altus	Pop. Center	Total	23,737	22,141	28,910	22,708	20,082	29,736
			Urban	4,821	4,527	8,439	8,593	9,735	21,225
			Rural	18,916	17,614	20,471	14,115	10,347	8,511
0-12	Frederick	Rural	Total	49,119	69,209	66,863	60,178	46,621	36,739
			Urban	5,955	10,058	4,568	5,109	8,210	8,704
			Rural	43,164	59,151	62,295	55,069	38,411	28,035
0-13	Ardmore	Pop. Center	Total	25,358	40,247	41,419	43,292	36,445	39,044
			Urban	8,618	14,181	15,741	16,886	17,890	23,082
			Rural	16,740	26,066	25,678	26,406	18,555	15,962
0-14	Shawnee	Pop. Center	Total	168,703	196,691	274,457	247,746	178,561	142,408
			Urban	20,078	29,301	70,528	69,501	75,099	69,883
			Rural	148,625	167,390	203,929	178,245	103,462	72.525
0-15	Muskogee	Pop. Center	Total	73,858	116,782	122,987	116,015	110,134	98,811
			Urban	29,451	53,596	56,817	55,288	63,593	60,561
			Rural	44,407	63,186	66,170	60,727	46,541	38,250
0-16	Claremore	Rural	Total	85,045	90,864	90,930	101,245	87,013	83,511
			Urban	14,638	16,316	14,508	19,759	23,858	27,774
			Rural	70,407	74,548	76,422	81,486	63,155	55,737
0-17	Miami	Rural	Total	54,495	88,551	86,138	91,226	80,859	72,373
			Urban	5,798	19,033	18,445	17,220	4,750	5,840
			Rural	48,697	69,518	67,693	74,006	76,109	66,533
0-18	McAlester	Pop. Center	Total	47,650	52,570	50,778	48,985	41,031	34,360
			Urban	17,621	14,112	15,391	17,960	17,878	17,419
			Rural	30,029	38,458	35,387	31,025	23,153	16,941
0-19a	Poteau	Rural	Total	84,328	102,814	109,064	98,708	78,052	63,966
			Urban	-----	2,679	3,169	4,020	7,661	7,779
			Rural	84,328	100,135	105,895	94,688	70,391	56,187
0-19b	Hugo	Rural	Total	52,661	87,563	73,645	89,142	63,994	50,576
			Urban	4,582	9,435	7,853	12,852	13,161	11,254
			Rural	48,079	78,128	65,792	76,290	50,833	39,322
0-20	Durant	Rural	Total	72,015	96,361	70,918	85,184	62,053	50,384
			Urban	5,330	10,057	7,463	15,169	15.985	16,428
			Rural	66,685	86,304	63,455	70,015	46,068	33,956

Table I-9 (Continued)

Map Designation	Area	Type [a]	Component [b]	1910	1920	1930	1940	1950	1960
Texas									
T-1	Dalhart	Rural	Total	10,585	12,075	24,060	23,235	37,243	43.367
			Urban	2,543	2,618	7,311	4,441	13,029	24.429
			Rural	8,042	9,457	16,749	18,794	24,214	18.938
T-2	Amarillo	SMSA	Total	15,736	20,385	53,151	61,450	87,140	149,493
			Urban	9,957	15,494	44,836	52,645	78,510	143,833
			Rural	5,779	4,891	8,315	8,805	8,630	5,660
T-3	Pampa-Borger	Pop. Center	Total	6,424	8,462	44,683	49,604	63,160	73.735
			Urban	-----	-----	17,002	22,913	34,642	24,664
			Rural	6,424	8,462	27,681	26,691	28,518	49,071
T-4a	Canadian	Rural	Total	6,754	9,433	10,606	9,223	8,812	7,666
			Urban	-----	-----	-----	-----	2,700	-----
			Rural	6,754	9,433	10,606	9,223	6,112	7,666
T-4b	Childress	Rural	Total	39,074	52,420	81,560	61,046	54,468	39,958
			Urban	3,818	7,842	21,526	16,764	21,004	15,981
			Rural	35,256	44,578	60,034	44.282	33,464	23,977
T-5	Hereford	Rural	Total	15,997	21,540	36,320	33,700	39,099	54,669
			Urban	-----	-----	2,637	5,194	11,645	18,766
			Rural	15,997	21,540	33,683	28,506	27,454	35,903
T-6	Plainview	Pop. Center	Total	7,566	18,082	20,189	18,813	28,211	36,798
			Urban	2,829	3,989	8,834	8,263	14,044	18,735
			Rural	4,737	14,093	11,355	10,550	14,167	18,063
T-7	Vernon	Rural	Total	84,221	88,020	117,382	100,384	91,079	72,536
			Urban	6,322	8,833	21,671	22,100	27,807	24,510
			Rural	77,899	79,187	95,711	78,284	63,272	48,026
T-8	Wichita Falls	SMSA	Total	22,619	78,165	84,100	81,203	105,309	129,638
			Urban	8,200	50,123	53,684	53,514	69,583	117,399
			Rural	14,419	28,042	30,416	27,689	35,726	12.239
T-9	Graham	Rural	Total	42,517	40,106	43,719	41,734	34,461	33,023
			Urban	-----	5,107	9,119	8,672	16,271	19,255
			Rural	42,517	34,999	34,600	33,062	18,190	13,768
T-10	Weatherford	Rural	Total	77,904	68,945	57,096	49,998	54,739	54.785
			Urban	7,948	9,382	8,043	14,577	18,581	24,233
			Rural	69,956	59,563	49,053	45,421	36,158	30,552
T-11	Sherman	Pop. Center	Total	92,599	99,832	89,979	94,408	92,613	95,603
			Urban	33,668	40,743	38,478	42,388	48.900	60,819
			Rural	58,931	59,089	51,501	52,020	43,713	34,784
T-12	Dallas-Fort Worth	SMSA	Total	412,688	541,301	689,499	783,050	1,136,144	1,656,016
			Urban	197,100	310,794	483,753	547,429	874,570	1,500,353
			Rural	215,588	230,507	205,746	235,621	261,574	156,463
T-13	Paris	Pop. Center	Total	105,911	119,815	102,830	104,347	83,250	63,974
			Urban	16,113	26,253	21,304	25,027	28,692	28,334
			Rural	89,798	93,562	81,526	79,320	54,558	35,640
T-14	Greenville	Pop. Center	Total	122,549	135,008	126,989	124,426	103,547	93,797
			Urban	23,869	32,634	30,824	38,571	43,865	50,926
			Rural	98,680	102,374	96,165	85,855	59,682	42,871
T-15	Mineola	Rural	Total	55,855	66,590	63,612	62,849	48,167	39,737
			Urban	-----	-----	3,304	3,223	3,626	3,810
			Rural	55,855	66,590	60,308	59,626	44,541	35,927
T-16	Mt. Pleasant	Rural	Total	74,307	84,653	75,511	77,470	63,583	57,993
			Urban	3,137	10,025	9,133	11,539	13,837	18,807
			Rural	71,170	74,628	66,378	65,931	49,746	39,186
T-17	Texarkana	SMSA [c]	Total	62,414	69,513	78,593	83,704	88,698	83,467
			Urban	9,790	11,480	16,602	17,019	31,223	37,067
			Rural	52,624	58,033	61,991	66.685	75,475	46,400
T-18	Marshall	Pop. Center	Total	81,815	93,690	97,383	146,552	139.997	142,872
			Urban	19,122	22,533	21,239	49,185	67,570	84,216
			Rural	62,693	71,157	76,144	97,367	72,427	58,656
T-19	Henderson	Pop. Center	Total	47,370	53,444	56,547	63,536	61,598	53,291
			Urban	-----	-----	2,932	6,437	11,583	14,928
			Rural	47,370	53,444	53,615	67,099	50,015	38,363
Missouri									
M-1	Joplin	Pop. Center	Total	116,809	100,827	100,769	107,744	107,346	108,956
			Urban	61,573	51,745	53,827	59,151	61,272	62,769
			Rural	55,236	49,082	46,942	48,593	46,074	46,187
M-2	Aurora	Rural	Total	107,910	105,367	98,471	100,626	91,069	80,845
			Urban	8,325	7,781	7,974	10,867	11,417	12,406
			Rural	99,585	97,586	90,497	89,759	79,652	68,439

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Table I-9 (Continued)

Map Designation	Area	Type[a]/	Component[b]/	1910	1920	1930	1940	1950	1960
Arkansas									
A-1	Fayetteville	Pop. Center	Total	67,218	71,721	74,508	77,262	88,055	92,069
			Urban	7,291	11,249	10,948	17,845	34,080	43,632
			Rural	59,927	60,472	63,560	59,417	53,975	48,437
A-2	Harrison	Rural	Total	72,640	74,591	65,711	67,951	60,347	50,557
			Urban	-----	3,477	3,626	4,238	5,542	6,580
			Rural	72,640	71,114	62,085	63,713	54,805	43,977
A-3	Van Buren	Rural	Total	237,031	250,146	222,738	225,777	189,466	161,180
			Urban	9,608	17,303	26,652	28,287	36,745	41,112
			Rural	227,423	232,843	196,086	197,490	152,721	120,068
A-4	Fort Smith	SMSA	Total	52,278	56,739	54,426	62,809	64,202	66,687
			Urban	23,975	28,870	31,429	36,584	47,942	52,991
			Rural	28,303	27,869	22,997	26,225	16,260	13,696
A-5	Benton	Rural	Total	85,036	87,721	84,322	87,189	89,857	89,110
			Urban	9,476	13,549	15,058	17,380	25,613	32,422
			Rural	75,560	74,172	69,264	69,809	64,244	56,688
A-6	Hot Springs	Pop. Center	Total	27,271	25,785	36,031	41,664	47,102	64,697
			Urban	14,434	11,695	20,238	21,370	29,307	28,337
			Rural	12,837	14,090	15,793	20,294	17,795	18,360
A-7	Little Rock	SMSA	Total	139,485	169,794	201,881	221,186	272,760	324,353
			Urban	72,181	98,470	121,857	130,466	183,478	225,324
			Rural	67,304	71,324	80,024	90,720	89,282	99,029
A-8	Stuttgart	Pop. Center	Total	106,420	128,534	130,166	127,852	122,291	108,493
			Urban	2,740	12,710	11,360	17,756	22,863	26,449
			Rural	103,680	115,824	118,806	110,096	99,428	82,044
A-9	Texarkana	SMSA [c]/	Total	121,257	136,709	139,527	141,082	118,254	100,486
			Urban	9,294	18,128	22,415	25,103	33,595	37,216
			Rural	111,963	118,581	117,112	115,979	84,659	63,270
A-10	Magnolia	Rural	Total	43,164	49,604	47,727	49,691	43,551	37,100
			Urban	2,705	2,691	6,041	7,503	10,878	14,184
			Rural	40,459	46,913	41,686	42,188	32,673	22,916
A-11	El Dorado	Pop. Center	Total	52,497	50,317	85,690	81,612	82,737	81,159
			Urban	8,197	7,125	26,238	24,833	37,673	41,115
			Rural	44,300	43,192	59,452	56,779	45,064	40,044
A-12	Warren	Rural	Total	59,939	65,713	64,395	65,251	53,515	45,780
			Urban	2,794	2,996	5,739	5,945	6,369	10,642
			Rural	57,145	62,717	58,656	59,306	47,146	35,138
A-13	Crossett	Rural	Total	99,607	106,052	109,789	120,937	108,159	93,640
			Urban	-----	2,707	12,317	15,287	22,402	29,403
			Rural	99,607	103,345	97,472	105,650	85,757	64,237
Louisiana									
L-1	Shreveport	SMSA	Total	99,124	130,238	182,543	217,041	252,390	321,187
			Urban	31,017	49,979	86,281	113,452	157,155	226,592
			Rural	68,107	80,259	96,262	103,589	95,235	94,595
L-2	Ruston	Rural	Total	190,981	194,500	213,092	220,873	194,428	183,725
			Urban	6,302	12,233	17,408	21,820	31,327	46,819
			Rural	184,679	182,267	195,684	199,053	163,101	136,906
L-3	Monroe	SMSA	Total	44,616	49,630	78,026	86,739	106,751	135,372
			Urban	10,209	12,675	37,715	43,505	61,643	82,627
			Rural	34,407	36,955	40,311	43,234	45,108	52,745
L-4	Tallulah	Pop. Center	Total	132,175	146,802	176,694	202,305	184,521	176,256
			Urban	-----	-----	8,691	21,827	34,254	44,528
			Rural	132,175	146,802	168,003	180,478	150,267	131,728
L-5	Natchitoches	Pop. Center	Total	36,455	38,602	38,477	40,997	38,144	35,653
			Urban	2,532	3,388	4,547	6,812	9,914	13,924
			Rural	33,923	35,214	33,930	34,185	28,230	21,729
L-6	Alexandria	Pop. Center	Total	44,545	59,444	65,455	73,370	90,648	111,351
			Urban	11,213	17,510	26,637	31,363	41,336	58,532
			Rural	33,332	41,934	38,818	42,007	49,312	52,819
			Grand Total	6,136,404	7,080,553	7,986,031	8,144,916	8,435,867	9,333,115
			Urban	1,323,493	1,920,400	2,736,033	3,066,384	4,115,209	5,663,243
			Rural	4,812,911	5,160,153	5,249,998	5,078,532	4,320,658	3,669,872

a/ See section entitled "Study Area Definition," for criteria used in type classification and boundary selection of subareas.

b/ Urban population shown in this table reflects the population of towns and cities with a population of more than 2,500 and do not exactly conform in all cases to census urban-rural definition.

c/ The Texarkana SMSA population is a portion of the combined populations of subareas T-17 and A-9.

Source: Bureau of the Census [12]/

Production

Agriculture

The agricultural economy of the study area is influenced by many factors outside the Arkansas-Red River basins. In addition to satisfying local demands, agricultural production in the area is directed towards national and international markets. For example, in 1958, wheat exports amounted to 29 percent of U.S. production, while cotton, rice, and sorghum exports amounted to 24, 29, and 16 percent, respectively, of U.S. production. 13/ These are the major crops grown in the study area.

The number of farms and acres of cropland harvested have paralleled the declining trend of the United States, as shown in Table I-10. However, this decrease was accompanied by an increase in the total value of farm products sold. The study area is providing an increase in proportion of the livestock sold in the United States. A subarea tabulation of agricultural statistics appears in Table I-11.

There has been a phenomenal increase of irrigation in the study area in the past 15 years. Study area irrigated acreage was 5.2 percent of the U.S. total in 1944 and 13.4 percent in 1959. Most of this increase is the result of extensive ground water irrigation development in the High Plains portion of the study area.

Table I-10

Agricultural Statistics for the Study Area and the United States 1944-1959

	1944	1949	1954	1959
Number of Farms (1,000)				
Study Area Total	598	538	457	343
U.S. Total	5,967	5,648	5,087	3,704
Percent of U.S.	10.0	9.5	9.0	9.3
Acres of Cropland Harvested (1,000)				
Study Area Total	47,942	44,544	39,313	35,765
U.S. Total	403,000	409,000	399,000	391,000
Percent of U.S.	11.9	10.9	9.9	9.1
Acres of Irrigation (1,000)				
Study Area Total	1,060	1,927	3,144	4,458
U.S. Total	20,539	25,905	29,552	33,211
Percent of U.S.	5.2	7.4	10.6	13.4
Value of All Crops Sold*				
Study Area Total	864,303	1,041,428	968,342	1,226,236
U.S. Total	8,337,186	9,671,640	11,161,130	13,246,000
Percent of U.S.	10.4	10.8	8.7	9.3
Value of All Livestock and Livestock Products Sold*				
Study Area Total	760,740	795,749	795,717	1,358,302
U.S. Total	11,114,454	11,222,410	12,439,504	16,791,174
Percent of U.S.	6.8	7.1	6.4	8.1
Value of All Farm Products Sold*				
Study Area Total	1,625,043	1,837,177	1,764,059	2,584,538
U.S. Total	19,451,640	20,894,050	23,600,634	30,037,174
Percent of U.S.	8.4	8.8	7.8	8.5

*In 1,000's of 1960 Dollars.

Source: Bureau of the Census [14]

Table I-11

Study Area Agricultural Statistics by Subareas
1944-1959

Map Designation	Area	Value of All Crops Sold (In 1,000's of dollars) 1944	1949	1954	1959	Value of All Livestock Sold (In 1,000's of dollars) 1944	1949	1954	1959
Colorado									
C-1	Pueblo-Colo. Springs	2,934	5,034	3,189	4,730	6,567	11,281	9,284	15,723
C-2	Lamar	16,139	37,618	11,861	39,967	15,809	26,054	22,754	38,612
C-3	Canon City	1,211	1,165	549	855	4,374	7,750	6,218	9,665
C-4	Trinidad	7,733	9,795	5,720	9,317	9,173	19,397	14,579	28,059
New Mexico									
NM-1	Raton	850	872	273	897	4,709	10,932	7,324	12,220
NM-2	Clovis	5,893	13,141	5,509	10,375	8,341	16,786	15,402	25,100
Kansas									
K-1	Garden City	35,609	53,189	35,565	79,279	12,478	21,318	18,996	48,251
K-2	Larned	19,927	13,895	19,797	13,536	6,864	9,062	7,820	16,283
K-3	Dodge City	24,175	13,454	11,627	13,189	5,806	7,826	7,635	22,828
K-4	Medicine Lodge	14,170	15,911	10,042	12,216	9,298	17,105	14,548	25,714
K-5	Pratt	26,300	17,763	29,649	21,290	11,402	13,236	11,208	20,189
K-6	Great Bend	6,628	6,098	10,416	6,207	2,708	2,866	2,569	5,105
K-7	Newton	12,492	14,032	24,887	25,232	18,417	25,086	21,759	33,233
K-8	Wichita	16,241	20,090	31,329	35,072	23,231	34,495	29,883	46,370
K-9	Wellington	15,979	17,835	26,093	30,168	10,885	13,685	11,226	18,068
K-10	Eureka	2,782	6,403	5,739	6,449	17,430	25,682	25,097	38.811
K-11	Emporia	7,428	15,643	21,135	27,213	25,463	37,103	34,083	55,125
K-12	Coffeyville	595	1,409	3,166	3,406	2,606	3,456	2,743	6,460
K-13	Pittsburg	1,082	1,894	2,303	3,938	2,599	3,820	3,337	4.631
Oklahoma									
O-1	Guymon	24,895	36,055	13,711	24,010	9,067	16,115	12,758	24,522
O-2a	Woodward	12,773	16,988	10,959	15,899	11,344	13,210	11,303	19,417
O-2b	Clinton	32,649	47,206	42,433	45,104	18,957	17,168	13,553	25,245
O-3	Alva	22,061	26,632	26,929	33,112	11,646	13,315	12,878	24.260
O-4	Enid	6,770	8,995	11,507	11,808	3,831	4,383	3,005	5,156
O-5	Ponca City	3,513	6,342	9,764	9,726	3,487	4,385	3,401	5,303
O-6	Tulsa	5,840	4,804	3,207	3,590	16,655	19,672	17,029	22,297
O-7	Stillwater	13,249	15,177	17,452	18,654	14,721	19,120	16,716	27,220
O-8	Oklahoma City	6,374	8,996	9,899	10,014	8,596	10,853	13,095	14,760
O-9	Duncan	20,046	22,815	19,262	23,906	15,637	19,816	17,974	32,950
O-10	Lawton	1,764	2,247	2,052	1,664	3,259	4,061	3,262	5,012
O-11	Altus	4,752	9,635	9,775	7,919	1,789	1,805	1,702	3,936
O-12	Frederick	12,190	19,919	15,957	15,236	6,545	8,065	6,653	12,619
O-13	Ardmore	687	468	334	311	1,989	1,969	1,852	3,575
O-14	Shawnee	10,591	8,069	4,931	6,139	9,633	12,722	12,272	21,792
O-15	Muskogee	4,887	3,524	2,672	4,560	3,332	4,921	4,286	6,368
O-16	Claremore	4,688	3,774	4,886	5,484	11,045	16,099	14,659	24,721
O-17	Miami	1,268	1,881	2,612	3,815	5,302	7,905	7,732	14,121
O-18	McAlester	1,499	1,334	658	935	1,611	2,356	2,409	4,648
O-19a	Poteau	3,348	2,677	2,389	3,051	2,987	4,986	4,887	11,067
O-19b	Hugo	2,318	2,370	1,878	1,628	2,509	4,003	3,564	7,500
O-20	Durant	3,859	5,153	4,026	4,051	4,903	8,993	7,102	13,635
Texas									
T-1	Dalhart	38,030	38,419	16,796	28,796	14,193	21,924	16,131	38,745
T-2	Amarillo	6,609	8,681	7,982	7,455	4,753	7,946	6,246	12,159
T-3	Pampa-Borger	9,876	10,721	7,913	9,563	4,963	7,612	5,458	9,538
T-4a	Canadian	5,726	5,774	2,326	4,001	7,302	9,408	7,035	12,808
T-4b	Childress	17,527	46,187	27,683	28,728	11,267	15,898	8,706	15,792
T-5	Hereford	32,839	58,990	101,800	110,514	16,311	14,299	13,602	19.641
T-6	Plainview	6,148	25,676	47,833	46,962	3,426	3,101	2,994	6,353
T-7	Vernon	27,563	70,610	41,003	44,194	13,398	20,481	14,930	25,844
T-8	Wichita Falls	1,997	3,147	2,906	2,400	3,900	9,080	6,387	7,419
T-9	Graham	2,267	4,037	3,547	2,306	6,097	10,350	7,383	12,241
T-10	Weatherford	2,498	3,714	2,134	1,649	7,222	12,294	14,001	24,901
T-11	Sherman	7,182	8,030	7,209	6,633	5,422	7,549	7,165	11,224
T-12	Dallas-Ft. Worth	29,112	45,385	32,740	35,758	21,421	31,509	27,261	44,506
T-13	Paris	11,605	19,220	12,218	12,520	4,198	4,974	5,159	11,082
T-14	Greenville	13,499	20,741	12,505	12,714	6,243	8,610	9,748	19,911
T-15	Mineola	4,209	6,680	4,640	4,668	3,558	3,752	4,004	7,489
T-16	Mt. Pleasant	5,095	6,317	3,386	2,411	3,126	4,806	4,610	10,462
T-17	Texarkana	2,855	3,566	2,123	2,140	1,723	2,903	2,926	8,402
T-18	Marshall	2,361	3,638	1,606	1,486	2,286	3,789	3,936	8,286
T-19	Henderson	2,285	4,017	1,731	1,172	1,542	2,696	4,561	7,861
Missouri									
M-1	Joplin	2,099	3,572	4,318	5,824	7,421	9,797	8,312	10.857
M-2	Aurora	3,677	6,012	10,519	9,149	19,090	25,447	25,497	38,108
Arkansas									
A-1	Fayetteville	2,990	2,975	1,944	2,215	11,953	25,509	31,597	48,188
A-2	Harrison	1,282	1,293	928	1,557	6,217	9,263	11,815	19.789
A-3	Van Buren	11,978	11,032	9,776	10,967	9,217	12,597	19,919	35,338
A-4	Fort Smith	564	643	448	329	1,496	1,473	1,607	2,689
A-5	Benton	1,993	1,899	1,390	1,318	2,744	4,475	4,398	6,150
A-6	Hot Springs	203	127	104	127	992	965	1,005	1.745
A-7	Little Rock	12,155	14,826	20,042	23,614	3,026	3,180	2,712	3,195
A-8	Stuttgart	7,906	8,485	54,907	63,133	3,461	4,756	5,530	9.239
A-9	Texarkana	8 458	9,988	7,555	8,132	3.364	5,351	6,036	18,093
A-10	Magnolia	2,119	3,596	1,721	1,270	783	1,000	1.520	4.184
A-11	El Dorado	1,155	1,637	693	775	831	1,128	1,216	1.961
A-12	Warren	2,006	4,105	2,042	2,343	1,127	1,391	1,769	4,833
A-13	Crossett	15,805	1,075	37,066	46,429	1,758	3,107	3,256	6,143
Louisiana									
L-1	Shreveport	7,419	13,107	11,347	12,512	1,905	2,860	3,765	7.455
L-2	Ruston	9,991	13,480	8,471	7,554	3,227	7,187	9,560	18.006
L-3	Monroe	4,872	8,784	9,103	10,868	991	1,608	1,896	3.161
L-4	Tallulah	27,313	36,356	49,997	49,811	3,242	8,255	9,188	19.134
L-5	Natchitoches	3,695	4,252	3,902	4,567	379	1,053	1,916	3,658
L-6	Alexandria	2,806	4,457	6,790	5,342	1,335	2,724	2,951	4,832
	Grand Total	778,298	1,065,573	1,060,386	1,226,236	591,695	858,969	786,285	1.379.971

Table I-11 (Continued)

Map Designation	Area	Number of Farms 1944	1949	1954	1959	Cropland Harvested (1,000 acres) 1944	1949	1954	1959
Colorado									
C-1	Pueblo-Colo. Springs	2,473	2,312	1,934	1,663	242	236	152	148
C-2	Lamar	5,279	5,621	5,189	4,310	1,346	1,906	1,251	1,611
C-3	Canon City	2,439	2,060	1,877	1,435	152	146	82	107
C-4	Trinidad	3,298	3,084	2,790	2,180	262	311	208	233
New Mexico									
NM-1	Raton	3,447	2,530	2,057	1,638	133	101	48	54
NM-2	Clovis	3,329	2,972	2,763	2,227	753	763	405	386
Kansas									
K-1	Garden City	4,620	4,697	4,923	4,577	2,088	2,450	2,435	2,587
K-2	Larned	2,991	2,837	2,671	2,510	985	859	885	733
K-3	Dodge City	2,557	2,365	2,558	2,287	1,050	827	874	755
K-4	Medicine Lodge	2,375	2,368	2,290	1,993	828	800	694	628
K-5	Pratt	4,879	4,455	4,154	3,669	1,416	1,217	1,212	1,094
K-6	Great Bend	1,522	1,507	1,510	1,373	398	372	378	339
K-7	Newton	7,109	6,833	6,277	5,728	1,140	1,082	1,073	1,064
K-8	Wichita	10,874	10,124	8,798	7,689	1,464	1,327	1,312	1,335
K-9	Wellington	5,299	4,978	4,727	4,167	1,137	1,055	1,007	1,062
K-10	Eureka	5,571	5,136	4,407	3,799	554	486	469	416
K-11	Emporia	14,820	13,719	12,262	10,225	1,363	1,261	1,249	1,220
K-12	Coffeyville	2,706	2,208	2,045	1,571	166	139	145	146
K-13	Pittsburg	2,345	2,286	1,873	1,498	181	167	157	164
Oklahoma									
O-1	Guymon	4,082	4,060	3,684	3,269	1,608	1,662	1,266	1,170
O-2a	Woodward	6,163	5,596	4,887	4,022	1,030	900	770	678
O-2b	Clinton	13,746	12,068	10,342	8,421	1,923	1,705	1,563	1,262
O-3	Alva	7,095	6,698	6,114	5,359	1,287	1,189	1,091	1,129
O-4	Enid	2,636	2,525	2,261	1,996	425	406	374	399
O-5	Ponca City	2,485	2,366	2,045	1,738	331	309	286	301
O-6	Tulsa	10,577	7,762	5,826	4,586	476	297	244	191
O-7	Stillwater	13,430	11,231	9,947	8,065	1,134	939	829	772
O-8	Oklahoma City	8,176	6,452	5,473	4,246	513	431	376	347
O-9	Duncan	16,401	13,166	10,989	8,784	1,220	869	747	650
O-10	Lawton	1,918	1,696	1,477	1,224	192	156	138	96
O-11	Altus	1,842	1,630	1,572	1,193	284	252	272	168
O-12	Frederick	5,838	5,176	4,247	3,550	749	689	605	486
O-13	Ardmore	2,290	1,918	1,544	1,202	77	45	29	26
O-14	Shawnee	15,890	13,512	10,595	7,886	695	459	349	258
O-15	Muskogee	6,128	4,996	4,107	2,994	310	226	187	119
O-16	Claremore	10,991	9,142	7,925	6,475	695	498	456	373
O-17	Miami	8,822	8,319	6,663	5,397	281	222	176	171
O-18	McAlester	2,673	2,479	2,071	1,556	103	83	56	45
O-19a	Poteau	8,953	7,926	6,551	4,958	264	167	138	125
O-19b	Hugo	7,611	7,287	5,639	4,075	193	153	95	78
O-20	Durant	7,044	6,283	5,040	3,684	317	258	205	150
Texas									
T-1	Dalhart	2,147	1,916	2,114	1,918	1,574	1,502	1,267	1,176
T-2	Amarillo	1,139	1,048	1,078	910	340	328	330	276
T-3	Pampa-Borger	1,191	1,202	1,120	921	478	488	437	369
T-4a	Canadian	872	886	876	706	294	275	245	215
T-4b	Childress	5,683	5,371	4,613	3,668	1,138	1,162	947	694
T-5	Hereford	4,649	4,441	4,562	4,169	1,888	1,724	1,683	1,623
T-6	Plainview	1,482	1,873	1,703	1,535	394	479	465	481
T-7	Vernon	9,612	8,364	7,321	6,183	1,616	1,691	1,494	1,164
T-8	Wichita Falls	1,910	1,572	1,182	1,013	183	187	234	117
T-9	Graham	3,759	3,226	2,781	2,180	284	264	205	137
T-10	Weatherford	6,271	5,810	5,397	4,207	250	202	162	119
T-11	Sherman	6,417	5,573	4,515	3,758	425	376	326	295
T-12	Dallas-Ft. Worth	22,701	19,422	16,448	11,574	1,446	1,264	1,148	1,035
T-13	Paris	9,288	8,600	6,599	5,176	526	511	414	338
T-14	Greenville	12,580	9,767	7,775	6,194	604	561	474	364
T-15	Mineola	8,029	6,765	5,415	4,114	198	168	145	83
T-16	Mt. Pleasant	9,405	7,712	6,133	4,193	209	196	137	98
T-17	Texarkana	7,530	5,947	4,821	3,294	156	131	76	58
T-18	Marshall	9,110	7,912	6,046	3,658	164	123	69	41
T-19	Henderson	6,834	6,214	5,215	3,499	151	107	66	42
Missouri									
M-1	Joplin	6,646	6,252	5,508	4,449	306	259	244	232
M-2	Aurora	14,650	14,403	12,460	10,293	652	562	533	486
Arkansas									
A-1	Fayetteville	9,801	10,128	8,586	6,970	225	175	149	114
A-2	Harrison	9,972	10,162	8,098	6,532	203	181	130	106
A-3	Van Buren	25,392	24,018	18,395	13,741	644	588	438	339
A-4	Fort Smith	2,257	1,827	1,611	1,132	31	25	23	17
A-5	Benton	8,952	8,063	6,838	4,233	164	138	82	63
A-6	Hot Springs	1,651	1,316	1,078	726	23	14	6	5
A-7	Little Rock	9,825	8,363	6,244	2,933	257	253	244	129
A-8	Stuttgart	14,328	13,981	11,340	7,682	699	731	749	746
A-9	Texarkana	13,720	11,652	9,063	6,089	370	316	200	163
A-10	Magnolia	5,385	4,529	3,634	2,067	116	111	64	35
A-11	El Dorado	4,353	4,034	3,123	1,727	70	52	32	16
A-12	Warren	5,871	5,832	4,821	3,130	128	124	72	41
A-13	Crossett	14,466	13,474	10,229	5,426	413	466	442	442
Louisiana									
L-1	Shreveport	8,885	7,348	6,464	4,028	218	196	162	121
L-2	Ruston	21,178	18,844	17,061	10,081	461	327	224	132
L-3	Monroe	5,166	4,781	4,110	2,634	116	120	113	105
L-4	Tallulah	25,883	23,845	21,278	13,203	639	645	666	622
L-5	Natchitoches	2,940	3,564	3,169	1,761	70	82	73	52
L-6	Alexandria	3,341	3,855	3,665	2,338	72	62	60	57
	Grand Total	598,194	538,208	456,573	343,000	47,960	44,346	39,316	35,766

Source: Bureau of the Census [14]

Minerals

The most conspicuous single feature of the economy of the basins is the prominence of petroleum and natural gas extraction in the creation of wealth and employment. The study area ranks high on the national scale in both volume of production and sales value. In 1960, oil production reached 0.6 billion barrels and gas production reached 3.5 trillion cubic feet. The sales values were $1.7 billion and $½ billion, respectively. This extraction of petroleum and natural gas accounted for approximately one-fourth of the national production. [15] Figure I-10 reveals the general location of oil and gas extraction in the study area. [16] The study area has averaged producting about 15 percent of the value of minerals extracted in the United States since 1953, as shown in Table I-12. A detailed tabulation of value of minerals by subareas appears in Table I-13.

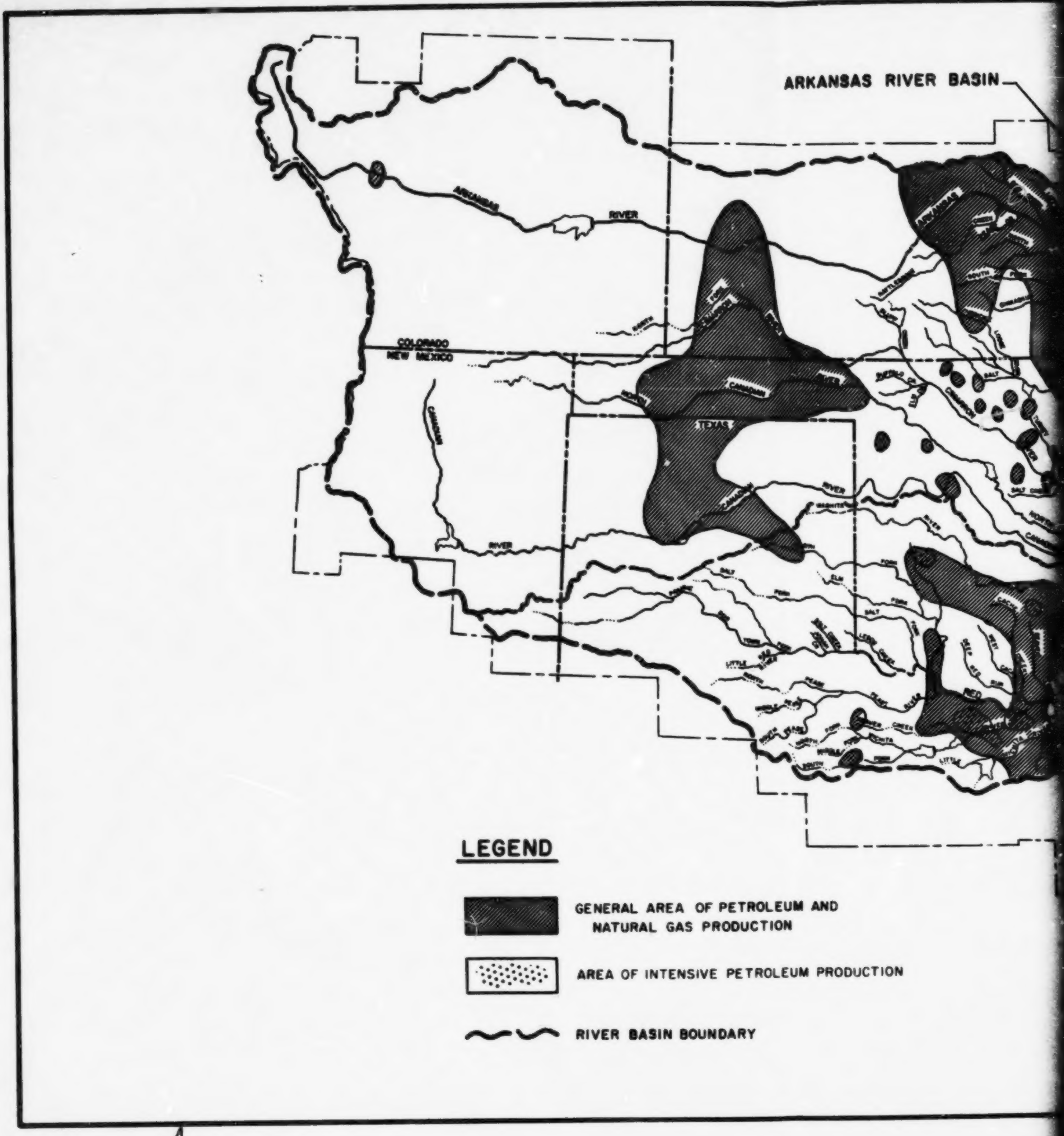
Table I-12

Value of Minerals Produced in the Study Area and the United States 1953-1960*

Year	Study Area Total	U.S. Total	% of U.S.
1953	2,457,781	14,983,186	16.4
1954	2,521,347	14,808,331	17.0
1955	2,524,783	16,654,243	15.2
1956	2,555,516	17,769,605	14.9
1957	2,527,720	17,585,912	14.4
1958	2,553,837	16,689,331	15.3
1959	2,595,081	17,408,238	14.9
1960	2,594,043	17,892,000	14.5

*In 1,000's of 1960 Dollars.

Source: Bureau of Mines [17]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GENERAL AREA OF PETROLEUM AND NATURAL GAS PRODUCTION
AREA OF INTENSIVE PETROLEUM PRODUCTION
RIVER BASIN BOUNDARY

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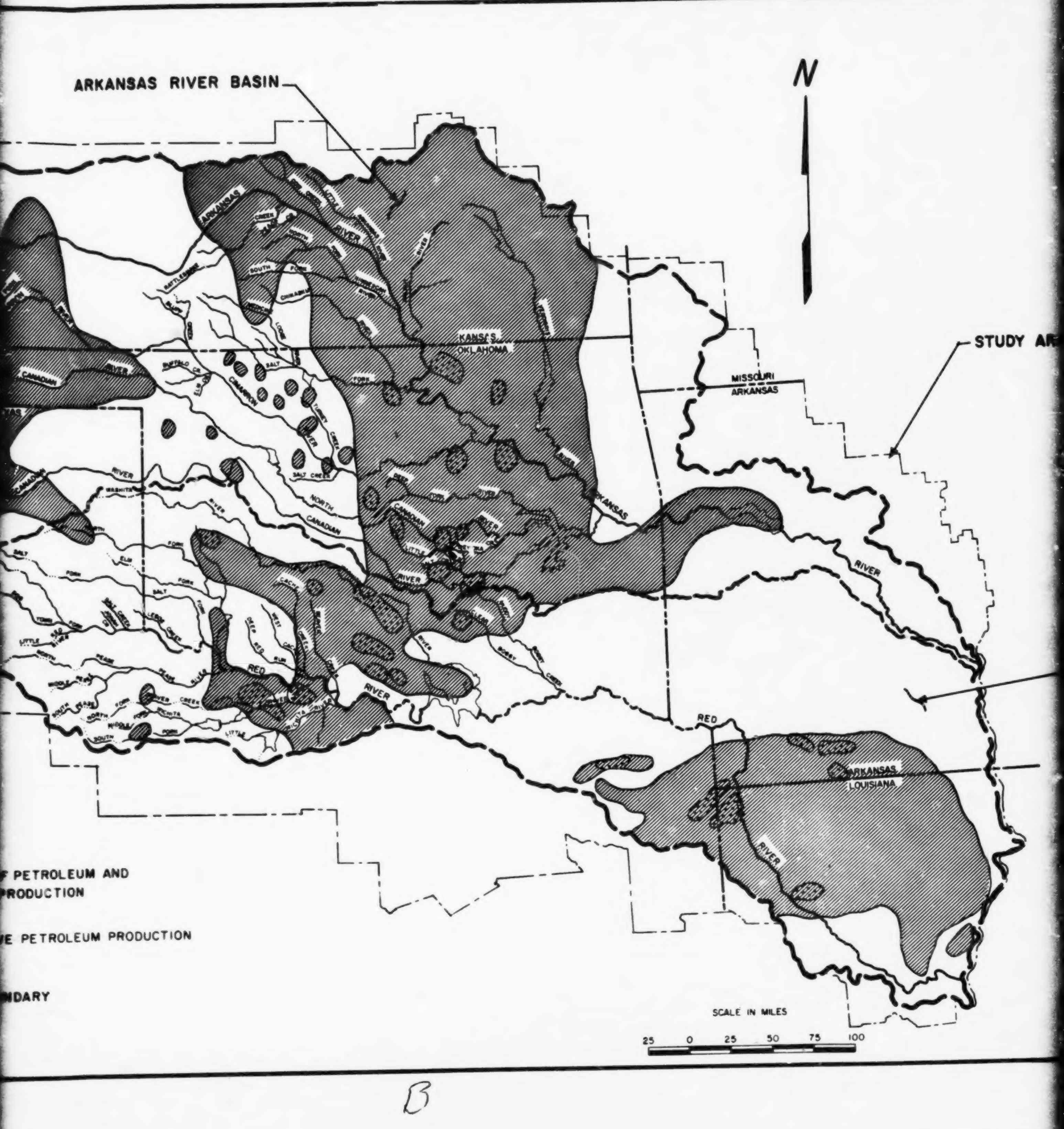
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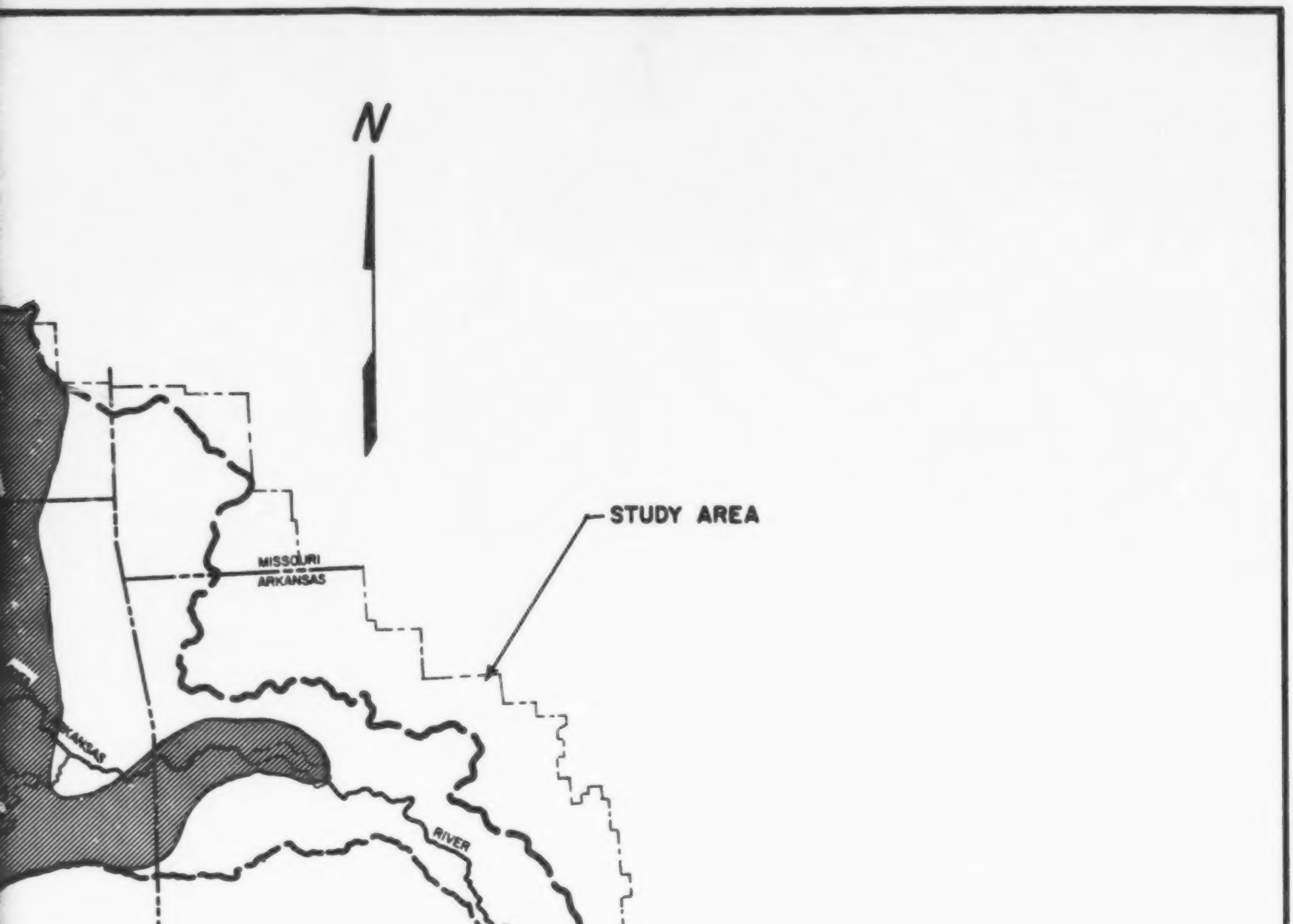
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ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

AREAS OF PETROLEUM AND NATURAL GAS PRODUCTION

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE 1–10

Table I-13

Study Area Value of Mineral Production by Subareas, 1953-1960*
($1,000)

Map Designation	Area	1953	1954	1955	1956	1957	1958	1959	1960
Colorado									
C-1	Pueblo-Colo. Springs	1,434	1,764	2,023	2,177	2,720	4,731	2,022	1,646
C-2	Lamar	235	643	252	723	410	756	355	1,024
C-3	Canon City	50,431	62,995	67,743	71,168	67,857	50,880	63,977	79,671
C-4	Trinidad	8,236	6,516	9,483	9,043	11,200	8,652	9,425	7,066
New Mexico									
NM-1	Raton	2,657	537	488	652	755	387	1,321	1,665
NM-2	Clovis	43	164	400	573	351	717	1,163	482
Kansas									
K-1	Garden City	41,360	48,041	55,764	58,482	51,664	59,904	70,845	79,880
K-2	Larned	5,561	7,206	10,435	14,411	14,285	11,719	8,738	7,462
K-3	Dodge City	563	516	433	677	718	1,095	1,007	1,409
K-4	Medicine Lodge	5,775	7,715	10,017	14,920	18,214	5,436	5,937	17,124
K-5	Pratt	49,799	51,892	48,086	43,510	27,992	52,121	45,648	43,816
K-6	Great Bend	45,618	46,634	40,565	41,775	39,736	35,553	34,102	30,791
K-7	Newton	21,609	23,894	25,525	25,053	27,658	19,822	28,598	28,846
K-8	Wichita	47,544	53,511	57,568	57,972	59,805	61,173	61,887	57,040
K-9	Wellington	6,610	8,678	14,737	17,779	11,400	-----	24,005	26,221
K-10	Eureka	19,635	22,829	23,697	25,064	26,533	25,488	22,518	19,995
K-11	Emporia	27,343	32,400	37,279	42,419	35,250	34,367	33,441	31.053
K-12	Coffeyville	6,693	8,120	9,264	8,179	6,554	6,560	7,144	4.781
K-13	Pittsburg	3,512	2,268	1,192	1,741	1,297	1,677	1,427	1,766
Oklahoma									
O-1	Guymon	20,092	26,514	25,207	31,481	30,880	36,725	44,480	60,243
O-2a	Woodward	-----	64	-----	3	1,445	1,345	1,723	809
O-2b	Clinton	28,003	19,068	29,170	26,416	19,845	20,287	16,924	16,957
O-3	Alva	6,260	4,997	5,487	5,333	7,190	9,209	10,074	12,732
O-4	Enid	5,249	6,441	7,279	7,784	8,605	7,390	6,812	6,308
O-5	Ponca City	9,803	11,289	12,519	12,119	13,930	13,824	13,418	15,407
O-6	Tulsa	80,734	86,63?	114,025	123,423	140,135	134,160	135,757	135,399
O-7	Stillwater	67,618	65,820	64,865	67,943	71,419	65,023	61,193	58,167
O-8	Oklahoma City	50,454	42,443	43,549	49,078	53,506	48,671	46,032	39,266
O-9	Duncan	186,707	160,229	178,757	203,766	227,347	205,926	217,978	223,057
O-10	Lawton	1,817	1,844	2,550	2,517	2,582	3,178	-----	3,007
O-11	Altus	886	1,570	1,964	1,007	1,168	564	709	613
O-12	Frederick	9,204	9,183	8,573	10,395	13,482	13,421	13,299	13,992
O-13	Ardmore	64,854	63,504	58,950	61,642	67,008	62,155	63,383	64,859
O-14	Shawnee	89,720	93,561	92,537	85,592	85,205	80,751	80,002	76,276
O-15	Muskogee	7,050	7,427	9,174	8,759	8,822	8,617	9,278	8,931
O-16	Claremore	15,355	17,078	19,739	22,724	24,178	21,812	18,349	14,677
O-17	Miami	11,275	13,989	15,153	13,064	6,474	2,954	1,033	1,712
O-18	McAlester	1,710	2,299	2,015	2,374	2,642	1,890	-----	-----
O-19a	Poteau	7,739	6,619	8,025	8,174	9,851	10,237	6,931	7,042
O-19b	Hugo	-----	-----	477	213	96	387	283	176
O-20	Durant	10,161	8,339	9,279	11,919	12,978	10,264	10,797	9,766
Texas									
T-1	Dalhart	46,514	55,479	47,097	51,946	67,634	63,457	98,416	102.477
T-2	Amarillo	5,004	7,495	6,416	7,145	15,362	6,536	12,672	10,463
T-3	Pampa-Borger	170,604	174,417	116,659	124,662	98,433	139,673	161,064	156,755
T-4a	Canadian	2,035	4,353	4,794	4,869	79	4,457	6,846	6,635
T-4b	Childress	7,055	6,921	5,368	5,232	8,352	7,363	10,982	9,614
T-5	Hereford	37	34	39	45	80	21	26	115
T-6	Plainview	7,321	6,651	7,215	7,247	6,118	5,449	6,348	4,904
T-7	Vernon	58,006	64,669	73,188	79,393	92,928	86,422	89,356	87,328
T-8	Wichita Falls	65,241	64,309	57,875	60,716	63,917	67,811	62,301	63,182
T-9	Graham	52,245	55,381	62,131	61,323	57,030	59,709	51,728	49,239
T-10	Weatherford	32,815	32,449	30,164	30,560	36,368	41,091	48,624	48,314
T-11	Sherman	39,163	44,840	51,685	56,854	56,063	56,340	45,580	52,202
T-12	Dallas-Ft. Worth	18,570	26,898	31,788	31,465	27,777	37,502	38,847	30,903
T-13	Paris	-----	14	41	14	35	-----	------	123
T-14	Greenville	12,378	15,076	12,531	12,681	9,193	10,846	8,244	8,075
T-15	Mineola	108,877	97,807	97,785	96,656	96,166	76,004	73,886	69,171
T-16	Mt. Pleasant	27,221	30,764	26,979	25,025	24,519	22,998	23,813	28,985
T-17	Texarkana	3,515	2,783	3,781	7,261	7,598	10,497	8,306	8,218
T-18	Marshall	197,456	185,275	182,462	181,252	226,843	159,520	145,653	134,289
T-19	Henderson	156,595	149,778	144,313	147,246	103,059	154,333	124,754	112,583
Missouri									
M-1	Joplin	4,058	3,163	2,614	3,181	2,797	2,543	2,674	2,726
M-2	Aurora	275	26	77	49	49	198	221	224
Arkansas									
A-1	Fayetteville	-----	-----	150	53	171	299	305	586
A-2	Harrison	-----	-----	46	1	13	84	-----	5
A-3	Van Buren	4,233	3,113	3,490	3,183	3,538	4,599	5,658	8,977
A-4	Fort Smith	2,679	1,243	2,161	3,066	2,712	1,028	1,784	1,470
A-5	Benton	17,939	21,549	19,938	18,335	17,307	15,150	22,760	24,666
A-6	Hot Springs	-----	-----	54	91	-----	63	68	246
A-7	Little Rock	4,309	4,870	8,065	9,323	7,995	7,678	8,991	5,847
A-8	Stuttgart	-----	-----	-----	16	-----	-----	70	40
A-9	Texarkana	20,572	21,777	20,811	22,470	24,413	20,109	23.228	23,508
A-10	Magnolia	28,677	26,672	24,624	25,069	30,315	28,834	28,514	31,252
A-11	El Dorado	37,608	40,688	40,027	39,538	43,157	40,079	33.630	34,423
A-12	Warren	493	571	[illegible]	577	377	537	677	1,494
A-13	Crossett	-----	-----	[illegible]	191	236	86	179	414
Louisiana									
L-1	Shreveport	76,952	85,401	69,542	64,425	105,158	103,569	91,943	96,198
L-2	Ruston	85,915	76,302	69,382	74,434	89,123	95,212	88,456	97,508
L-3	Monroe	4,327	4,246	4,917	5,141	4,250	5,976	7,733	10,488
L-4	Tallulah	43,235	41,705	37,385	41,659	58,221	49,806	51,181	56,961
L-5	Natchitoches	392	379	334	274	309	352	332	373
L-6	Alexandria	3,405	2,789	2,866	2,816	2,599	3,244	2,280	1,931
	Grand Total	2,365,070	2,395,123	2,394,067	2,497,328	2,603,481	2,529,303	2,570,151	2,594,044

* Data does not include figures withheld to avoid disclosing individual company confidential data.

Source: Bureau of Mines 17/

Forestry

Most of the eastern portion of the study area is covered by forests. Studies by the Forest Service indicate that 62 percent of the land area of Arkansas and 56 percent of Louisiana are covered by forests. 18 19/ Forests are also prevalent in eastern Oklahoma and portions of Texas within the study area.

There is a trend toward more growing stock of softwoods with a decrease in hardwoods. This fact is especially true in Arkansas and Louisiana where hardwoods, which usually grow in the alluvial flood plains, are being cleared for agricultural crop production. The increase of softwoods is occurring in the uplands where extensive restocking of pines to replace hardwoods is being promoted. The hardwood is used primarily for flooring, furniture, veneers, poles, pilings, and cooperage. Most of the softwood is used by the pulp and paper industry, the area's fastest growing segment of the forest industry.

The study area has produced about 7 percent of the Nation's pulpwood since 1946 as shown in Table I-14. Pulpwood production in the study area has nearly doubled from 1946 to 1959 with Arkansas and Louisiana being responsible for most of this increase.

Table I-14

Pulpwood Production Arkansas-Red River Basins Study Area and the United States 1946-1959
(1,000 Cords)

State	1946	1951	1955	1959
Arkansas	572	602	871	1,177
Louisiana	594	679	1,036	1,100
Oklahoma	13	45	38	38
Texas	111	228	207	184
Study Area Total	1,290	1,554	2,152	2,499
U.S. Total	16,982	25,128	30,948	36,716
Percent of U.S.	7.6	6.2	6.9	6.8

Source: Forest Service 20/

Manufacturing

Value added by manufacturing (1960 dollars) in the study area has shown a 340 percent increase from 1939 to 1958 compared to a 167 percent increase in the United States during the same period. Trends shown in Table I-15 indicate the increasing importance of the study area in the manufacturing segment of the national economy. Important components of the manufacturing sector include production and associated byproducts of petroleum, natural gas, petrochemicals, iron and steel, aluminum, pulp and paper, and food and kindred products. Table I-16 is a tabulation of value added by manufacturing for subareas.

Table I-15

Value Added by Manufacturing for the Study Area and the United States 1939-1958*

Year	Study Area Total	U.S. Total	% of U.S.
1939	924,101	54,072,865	1.7
1947	2,074,008	100,009,198	2.1
1954	3,488,910	131,134,356	2.7
1958	4,081,151	143,841,114	2.8

*In 1,000's of 1960 dollars.

Source: Bureau of the Census 21/

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Table I-16

Study Area Value Added by Manufacture Ly Subareas 1939-1958*

($1,000)

Map Designation	Area	1939	1947	1954	1958
Colorado					
C-1	Pueblo-Colo. Springs	17,057	44,099	90,098	120,835
C-2	Lamar	410	2,605	2,059	1,831
C-3	Canon City	1,389	3,722	7,956	11,704
C-4	Trinidad	1,862	4,505	4,214	6,718
New Mexico					
NM-1	Raton	315	1,092	1,677	3,252
NM-2	Clovis	479	1,237	2,254	3,624
Kansas					
K-1	Garden City	712	3,207	3,553	4,705
K-2	Larned	130	824	603	602
K-3	Dodge City	449	2,125	3,508	7,362
K-4	Medicine Lodge	-----	96	268	292
K-5	Pratt	954	2,040	3,254	4,315
K-6	Great Bend	785	4,534	2,519	3,372
K-7	Newton	3,640	17,271	39,026	23,274
K-8	Wichita	28,535	132,972	388,107	523,582
K-9	Wellington	621	2,668	3,045	3,500
K-10	Eureka	85	455	703	1,357
K-11	Emporia	6,486	32,561	61,014	58,480
K-12	Coffeyville	9,165	23,460	37,186	42,642
K-13	Pittsburg	1,740	6,774	8,250	10,006
Oklahoma					
0-1	Guymon	28	43	570	766
0-2a	Woodward	1,223	3,827	5,755	954
0-2b	Clinton	1,265	4,179	3,515	5,423
0-3	Alva	432	1,472	1,788	1,639
0-4	Enid	4,432	17,732	14,320	26,432
0-5	Ponca City	5,422	24,612	46,785	54,354
0-6	Tulsa	34,406	114,276	233,216	270,854
0-7	Stillwater	3,120	8,756	14,257	15,035
0-8	Oklahoma City	26,627	77,979	112,062	143,540
0-9	Duncan	1,033	8,643	21,929	5,174
0-10	Lawton	-----	-----	4,635	5,958
0-11	Altus	-----	1,117	996	1,509
0-12	Frederick	75	69	759	189
0-13	Ardmore	878	2,292	4,265	4,178
0-14	Shawnee	5,406	11,526	22,539	34,797
0-15	Muskogee	5,854	21,381	37,923	38,590
0-16	Claremore	400	1,208	6,498	12,981
0-17	Miami	32	287	841	1,233
0-18	McAlester	615	2,019	4,228	4,963
0-19a	Poteau	851	1,662	2,182	3,033
0-19b	Hugo	2,253	4,212	3,327	5,519
0-20	Durant	468	1,063	2,057	1,841
Texas					
T-1	Dalhart	1,988	8,513	25,685	31,129
T-2	Amarillo	3,876	14,985	24,773	37,735
T-3	Pampa-Borger	7,691	75,071	67,668	21,669
T-4a	Canadian	-----	128	27	-----
T-4b	Childress	543	1,166	1,837	351
T-5	Hereford	127	760	1,046	1,629
T-6	Plainview	795	3,303	5,351	3,121
T-7	Vernon	1,671	4,927	7,395	2,622
T-8	Wichita Falls	5,325	21,648	26,350	28,193
T-0	Graham	552	1,688	1,354	22,995
T-10	Weatherford	1,098	3,363	5,443	8,989
T-11	Sherman	5,580	26,325	35,872	45,898
T-12	Dallas-Ft. Worth	94,353	400,541	904,323	1,357,294
T-13	Paris	2,326	7,081	16,493	24,184
T-14	Greenville	3,118	8,249	18,621	28,872
T-15	Mineola	414	1,078	5,286	5,379
T-16	Mount Pleasant	1,936	3,657	26,377	9,963
T-17	Texarkana	4,103	11,632	22,883	17,285
T-18	Marshall	5,846	20,986	31,989	71,747
T-19	Henderson	711	2,342	2,518	3,318
Missouri					
M-1	Joplin	9,996	27,773	50,483	71,423
M-2	Aurora	1,683	4,227	19,994	25,246
Arkansas					
A-1	Fayetteville	1,242	8,335	18,118	26,631
A-2	Harrison	236	2,190	3,418	3,655
A-3	Van Buren	3,465	10,043	19,710	31,737
A-4	Fort Smith	8,033	4,737	40,887	52,623
A-5	Benton	2,931	20,588	65,390	76,270
A-6	Hot Springs	1,321	3,670	4,772	8,557
A-7	Little Rock	12,907	47,506	82,174	129,761
A-8	Stuttgart	2,204	7,132	18,143	16,005
A-9	Texarkana	1,988	12.018	15,724	19,296
A-10	Magnolia	1,731	5,417	5,459	8,456
A-11	El Dorado	9,051	46,260	83,358	70,891
A-12	Warren	2,231	5,202	13,872	13,929
A-13	Crossett	4,206	16,525	24,144	31,657
Louisiana					
L-1	Shreveport	11,538	36,311	115,491	115,473
L-2	Ruston	4,794	20,233	19,234	26,425
L-3	Monroe	6,588	25,646	51,540	53,264
L-4	Tallulah	2,338	8,996	8,411	12,946
L-5	Natchitoches	855	2,142	1,360	1,005
L-6	Alexandria	4,246	13,643	16,994	20,664
	Grand Total	405,271	1,540,639	3,113,708	4,008,202

* Data does not include figures withheld to avoid disclosing individual company confidential data.

Source: Census of Manufactures 21/

Petroleum

The petroleum industry in the Arkansas-Red River basins has been a significant factor in the growth of the area since the discovery of oil in eastern Kansas and northeastern Oklahoma nearly 60 years ago. As shown in Table I-17 the study area accounted for 15 percent of the Nation's oil refineries with 10 percent of the Nation's refinery capacity in 1961. The study area also contained 17 percent of the Nation's oil reserves and produces approximately one-fourth of the Nation's petroleum. 17 22/ Presently much of the oil produced is processed outside the study area.

Table I-17

Refineries, Refinery Capacities, and Petroleum Reserves for the Study Area, Eight States and the U.S. 1960

	Oil Refineries		Capacity		Proved Recoverable Reserves	
Area	Number	% of Total	Bbl/day	% of Total	Billion bbl.	% of Total
Study Area	46	15.4	957,860	9.6	6.4	16.8
(Eight States)*	118	41.0	4,355,097	43.8	28.0	73.8
Total U.S.	298	100.0	9,933,725	100.0	38.0	100.0

*Totally or partially within the basins.

Source: The Oil and Gas Journal 22 23/

Natural Gas

The natural gas processing industry has been actively developed in the study area since the turn of the century and is still one of the major sources of income for the area. With three of the Nation's largest gas fields (Hugoton, Panhandle, and Monroe - Richland) encompassed by its boundaries, the study area accounted for 28 percent of the total U.S. reserve (262.6 trillion cubic feet) in 1961. 24 25/ Thirty-one percent of the U.S. processing capacity (40.5 billion cubic feet/day) is in operation at 176 gas refineries in the study area. 26/ Table I-18 shows the study area gas refineries and their capacities as well as gross withdrawals and estimated gas reserves.

The natural gas processing industry exerts a significant water demand in the production of natural gasoline and light hydrocarbon streams from natural gas.

The natural gasoline and light hydrocarbons (liquefied gases and ethane) separated from natural gas in natural gasoline plants are commonly referred to as Natural Gas-Liquids. 15/

Table I-18

Gas Refineries, Major Gas Reserves,[a] and Gross Withdrawals in the Arkansas-Red River Basins Study Area, 1958 and 1961

State	Study Area	Gas Refineries Number	Gas Refineries Capacity 1961 (Million cf/d)	Gross Withdrawals 1958 (Million cf)	1961 Total Reserves (million cf) Study Area	1961 Total Reserves (million cf) State
	-------------Counties-------------					
Arkansas	Franklin					
	Columbia					
	Lafayette	7	439			
	Pope					
	Sebastian					
	Union					
	Plus 7 Counties of Less Significance					
	TOTAL	7	439	48,000	1,440,000	1,440,000
Oklahoma	Entire State	53	2,200			
	(Major Counties)					
	(Texas [b])					
	(Beaver)					
	(Garvin)					
	(Oklahoma)					
	(Beckham)					
	TOTAL	53	2,200	719,794	17,400,000	17,400,000
Kansas	Hugoton Area:					
	Finney					
	Grant					
	Hamilton					
	Haskell					
	Kearny	8	1,605		15,000,000 [c]	
	Morton					
	Seward					
	Stanton					
	Stevens					
	South Central	4	235		5,000,000	
	TOTAL	12	1,840	562,000	20,000,000	20,500,000
	--------------Fields--------------					
Louisiana	North La. Area (Except Major Fields)				3,536,000	
	Major Fields:					
	North La.	21	1,209		1,400,000	
	Ark., La., & Texas [d]				1,300,000	
	E. Texas & N. La. [e]				1,100,000	
	Monroe	2	375		300,000	
	TOTAL	23	1,584	210,000 (Prorated)	6,236,000 [f]	67,500,000
Texas	East Texas Area (Except Major Fields)				3,135,000	
	Major Fields:					
	East Texas	25	1,900		3,350,000	
	Ark., La., & Texas [d]				1,300,000	
	E. Texas & N. La. [e]				1,100,000	
	Hansford County	36	4,100		389,000	
	Panhandle - Hugoton [c]				37,000,000	
	North Texas	20	619		400,000	
	TOTAL	81	6,619	1,340,000 (Prorated)	28,174,000 [g]	122,500,000
Study Area	TOTAL	176	12,702		73,250,000	
Eight States [h]	TOTAL	495	34,957			248,875,000
United States	TOTAL	633	40,520			262,600,000

[a] Only the individual reserves with cumulative production of at least 100 billion on January 1, 1960, are listed separately here. In other words, the total reserves shown in the study area for Texas and Louisiana would increase considerably if all known reserves were included.

[b] Texas, Beaver, and Beckham Counties are in part of the above field. Total gas reserves in major fields in the Arkansas-Red River basins - approximately 73 trillion cubic feet.

[c] The Panhandle - Hugoton area includes counties in Texas, Oklahoma, and Kansas. Since the actual amount of this large reserve included in each State is not known, for estimating purposes the reserve is assumed divided approximately as follows: Texas, 50 percent; Kansas, 40 percent; and Oklahoma, 10 percent. Of the 37 trillion cubic feet total, Texas would then have about 18.5 trillion cubic feet in the reserve, Kansas about 14.8 trillion cubic feet, and Oklahoma about 3.7 trillion cubic feet.

[d] Since the exact breakdown is not known, the reserves in this field are assumed equally divided among the areas listed.

[e] Same as above.

[f] This figure is less than the column total (Notes d and e).

[g] This figure is less than the column total (Note c).

[h] These totals are for the entire States of Colorado, New Mexico, Kansas, Oklahoma, Texas, Missouri, Arkansas, and Louisiana.

Source: The Oil and Gas Journal [24 25]

Petrochemical

Much of the past economic growth of the Arkansas-Red River basins, and the Nation as well, has been attributed to development of natural resources (petroleum and natural gas in particular). With the development of these resources and considerable progress in technological know-how spurred on by increased demands for new and better fibers, materials, detergents, fertilizers, fuels, etc., the petrochemical industry developed. Petrochemicals are chemical compounds or chemical elements recovered in whole or in part from petroleum or natural gas and intended as raw materials for the chemical processing industry. [27,28] Petrochemicals accounted for about 30 percent of all national chemical production in 1960. [29] The Nation produced about 56 billion pounds of petrochemicals valued at $6.9 billion or 61 percent of the total value of all chemicals in 1960.

Petrochemical production in the study area in 1960 accounted for about 9 percent (approximately 5 billion pounds) [29] of the total U.S. production. That the industry has experienced a rapid growth in the area is pointed up by the increase in number of plants from 2 to over 45 since 1940. [29,30]

Iron and Steel

The iron and steel industry in the Arkansas-Red River basins has become firmly implanted in two major locations, Pueblo, Colorado, and Lone Star, Texas. With operations dating back more than 88 years, the plants are becoming completely diversified, serving all of the southwest and other parts of the country. The two plants have a steel ingot capacity, including expansion now in progress, totaling 3.2 million net tons per year. [31,32] Total production in 1960 amounted to approximately 2.1 million tons. [33,34]

The largest of Colorado Fuel and Iron's nationwide network of 11 steel plants is the Pueblo plant which has a steel ingot capacity of 1.8 million net tons and will soon be increased by 0.6 million net tons. [31] A completely diversified plant, the Colorado plant manufactures over 1,300 products for distribution throughout the world. The plant has had an average steel production since 1950 of 1.3 million net tons. [35,36] Iron ore used by the plant comes from company mines in Wyoming, Utah, and New Mexico and foreign imports. Coal used by the plant comes from the following sources: Colorado Fuel and Iron's mines in Colorado and New Mexico, privately owned mines in Colorado and New Mexico, and mines in Arkansas and West Virginia.

The rebuilding of the present steel industry in east Texas in the early 1940's resulted from the increased demands for steel for production, refining, and transmission equipment in the petroleum industry. 37/ The largest and most important iron ore deposits in the Arkansas-Red River basins are in northeast Texas. These deposits are the only resources of the basins having sufficient size and grade to support an integrated iron and steel mill. 27/ Existing industry has become firmly established on the basis of regional demand for its products, adequate iron ore reserves, and availability of large supplies of other necessary raw materials such as coking coal and limestone and dolomite within economic shipping distances from the furnaces.

Aluminum

Present aluminum production in the study area is confined to Clark and Hot Spring Counties in Arkansas. Alumina reduction plants are located near Arkadelphia and Jones Mills and have a capacity of 164,000 short tons per year (6.8 percent of the U.S. capacity). 38/

The most important deposits of bauxite, the principal ore used in the production of alumina, occur near Little Rock and Bauxite, Arkansas. Centers of the two bauxite areas, which cover about 15 square miles, are approximately 14 miles apart. In 1959, 96 percent of the U.S. production was produced from these deposits. 38/ The Arkansas deposit is not homogeneous and would, therefore, vary in its value as alumina feedstock. 27/

Present bauxite reserves in Pulaski and Saline Counties are estimated to be approximately 50 million tons (mined and dried equivalent). The Bureau of Mines 27/ estimated that as of January 1, 1946, the bauxite reserve contained:

Approximately 40 million long tons of 32 percent aluminum bauxite (mined and dried equivalent)

Approximately 25 million tons of submarginal bauxite

Approximately 3.5 million tons of high iron bauxite

Approximately 63,300,000 tons of bauxitic clay

Bauxite production in the study area since 1946 has totaled about 20.3 million tons. 30 38/ During this period about 5.5 million tons of new reserves have been developed. It is assumed that as of January 1, 1960, the reserve of bauxite on a mined and dried basis that can be used economically under existing conditions was approximately 50 million tons. If the rate of production experienced from 1950 to 1960 38/ by this area continues, the estimated reserve will be depleted in about 31 years. However, aluminum industries now operating in the area could import bauxite or alumina from mines in Jamaica, Haiti, and other overseas locations of bauxite reserves. 38/

Pulp and Paper

The pulp and paper industry is centered in the eastern portion of the study area. Eleven mills, with combined capacities of 6,050 tons/day (7 percent of all woodpulp mill capacities in the United States) are located in the study area as follows: 5 mills in Louisiana with combined capacity of 3,785 tons/day; 4 mills in Arkansas with combined capacities of 2,135 tons/day; 1 mill in Oklahoma with a capacity of 90 tons/day; and 1 mill in Texas with a capacity of 40 tons/day. 39/ Table I-19 shows subarea pulpwood production as well as the location of paper mills and their capacities.

Food and Kindred Products

The food and kindred products industry processes meat and dairy products, canned and frozen foods, grain mill products, beverages, and other food preparations. Since the study area has essentially an agriculturally oriented economy, a large portion of the manufacturing output is accounted for by this industry. In the study area, food and kindred products industry employment in 1950 amounted to 16 percent of all manufacturing employment. 11/

Most of the food processing in the study area is accomplished by small plants serving local populations. In terms of income and employment, however, the major industries of this classification are meat packing, flour milling, canning and fruit processing, and poultry processing. Some of these plants are of large scale proportions, such as the meat packing plants in Wichita, Oklahoma City, and Fort Worth; poultry processing plants in northwestern Arkansas; rice processing plants near Stuttgart, Arkansas; and flour mills in Hutchinson and Wichita, Kansas.

Table I-19

Commercial Forests, Pulpwood Production, and Paper Mill Capacities for the Study Area 1958 and 1959

Map Designation	Area	Total Land Area 1,000 Acres	Commercial Forests Area - 1,000 Acres		1959 Pulpwood Production		1958 Paper Mill Capacity No. of Plants/ Tons Per Day
			Total	Estimated Softwood	Total	Cords per Day	
Oklahoma							
O-16	Claremore	433	149	5	8,816	24	1/90
O-17	Miami	1,621	983	74	31	0*	
O-19a	Poteau	2,323	1,410	1,190	7,399	20	
O-19b	Hugo	2,599	1,920	1,070	21,851	60	
Texas							
T-12	Dallas-Ft. Worth						1/40
T-15	Mineola	1,010	244	164	3,624	10	
T-16	Mt. Pleasant	1,405	649	113	23,192	64	
T-17	Texarkana	1,207	661	164	43,730	120	
T-18	Marshall	815	465	216	59,946	164	
T-19	Henderson	1,167	631	306	53,748	147	
Arkansas							
A-2	Harrison	2,268	1,707	178	156	0*	
A-3	Van Buren	4,815	3,595	1,920	73,528	202	
A-4	Ft. Smith	339	138	45	11	0*	
A-5	Benton	2,472	2,055	1,420	164,657	451	
A-6	Hot Springs	437	371	257	15,650	43	
A-7	Little Rock	1,060	565	232	29,792	82	2/880
A-8	Stuttgart	2,668	1,169	68	1,673	5	
A-9	Texarkana	2,698	1,951	1,200	154,308	423	
A-10	Magnolia	886	650	354	89,731	246	
A-11	Eldorado	1,146	955	503	165,082	452	1/600
A-12	Warren	2,036	1,745	1,020	313,904	860	
A-13	Crossett	2,405	1,516	670	168,083	460	1/655

Table I-19 (Continued)

Commercial Forests, Pulpwood Production, and Paper Mill Capacities for the Study Area 1958 and 1959

Map Designation	Area	Total Land Area 1,000 Acres	Commercial Forests Area - 1,000 Acres		1959 Pulpwood Production		1958 Paper Mill Capacity No. of Plants/ Tons Per Day
			Total	Estimated Softwood	Total	Cords per Day	
Louisiana							
L-1	Shreveport	1,509	905	312	129,060	354	2/1,480
L-2	Ruston	4,905	3,717	2,080	716,304	1,960	1/580
L-3	Monroe	926	627	168	67,638	185	2/1,725
L-4	Tallulah	3,361	2,149	76	60,512	166	
L-5	Natchitoches	830	623	316	74,023	202	
L-6	Alexandria	851	645	226	52,744	144	

*Less than one cord per day.

Source: Forest Service 20 39/

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II. DESCRIPTION OF PROBLEM

Mineral Pollution and Its General Origin

The harmfulness of infecting organisms and toxic contaminants is self-evident in dealing with any potential source of water supply. There are other water quality parameters, however, that fall between wholesomeness and contamination and so cannot directly be incriminated as a pollutant. Such a quality parameter is dissolved mineral solids.

Highly mineralized waters often possess laxative properties, particularly when associated with magnesium and sulfate ions. Mineralized waters tend to be hard, consuming soap; however, this factor has become less significant with the advent of detergents. Although most mineral waters are less corrosive than soft waters, the water is very corrosive when the minerals involved contain principally chlorides or sulfates. In this report, primary concern is with those aspects of water quality affected by chlorides and sulfates.

In its common usage, the word "salt" refers to table salt, which is 98 percent or more sodium chloride ($NaCl$). The chemical definition of salt, however, includes a large number of compounds such as gypsum (calcium sulfate), epsom salts (magnesium sulfate), Glauber's salt (sodium sulfate), calcium chloride, and magnesium chloride, all of which are naturally occurring minerals in these basins. In this report, the term "salt" refers only to sodium chloride, and the chemical or generic name will be used to refer to the other compounds. As shown in Table II-1, all of these compounds are highly soluble except gypsum whose solubility is, nevertheless, large enough to be greatly degrading to natural waters.

The domestic, industrial, and agricultural uses of salt are many. In addition to the regular use of salt in the home, it is commonly used in raising livestock, road deicing, and water softener regeneration. Fertilizers and other agricultural materials may contain gypsum or sodium compounds in addition to the phosphate, nitrate, and other plant nutrients. These materials reach water courses in sewage discharges or in the runoff from the fields and streets. Meat packing plants and canneries use and may waste salt; steel mills use sulfuric acid and caustic (sodium hydroxide, $NaOH$), some of which may reach the stream. Limestone ($CaCO_3$) and gypsum quarries may produce solid or waterborne wastes with these constituents or other mineral impurities. Salt manufacturing plants (where the source is other than a natural brine emission) may discharge waters containing salt, gypsum, and other minerals. Chlorine works and other chemical plants may have mineral wastes.

Table II-1

Solubility of Mineral Compounds Found in Arkansas-Red River Waters

Compound	Formula	Approx. Solubility in Distilled Water at Room Temperatures	Remarks
Salt (sodium chloride)	$NaCl$	26% (190,000 mg/1 of Cl)	Solubility increases slightly as temperature rises.
Gypsum (calcium sulfate)	$CaSO_4$	0.2%	Solubility increases to 7,200 mg/1 (0.7%) as salt content of water increases.
Calcium Chloride	$CaCl_2$	37%	Solubility increases considerably as temperature increases.
Magnesium Chloride	$MgCl_2$	35%	Solubility increases considerably as temperature increases.
Epsom Salts (magnesium sulfate)	$MgSO_4$	20%	Solubility increases considerably as temperature increases.
Glauber's Salt (sodium sulfate)	Na_2SO_4	5%	Solubility increases considerably as temperature increases.

Source: Handbook of Chemistry and Physics 1/, and Solubility of Inorganic and Metal Organic Compounds 2/

All of these possible salt sources exist in the Arkansas-Red River basins, but the estimated amount of salt contribution by these sources is less than 5 percent of the total in the streams. The major sources of mineral pollution in the Arkansas-Red River basins are natural brine emissions and oil and gas production resulting in brine releases.

Chlorides and sulfates are the dominant constituents in the natural brines of the study area. In general, if sodium, chloride, and sulfate ions reach a stream, they will remain dissolved with little or no precipitation by natural causes. On the other hand, calcium carbonate, magnesium carbonate, and magnesium hydroxide have very low solubilities in natural waters and may be precipitated naturally thereby resulting in a mineral loss.

Impairment of Water Uses

High concentrations of mineral solids in the waters of the Arkansas-Red River basins limit the usage of these waters. This limitation can be a detrimental factor in economic growth and can become more acute as future water demands develop.

The drought of the 1950's necessitated the undesired use of large amounts of mineralized waters of the Arkansas-Red River basins. Exhaustion of Dallas' normal surface water source forced the city to augment that source with water from the Red River. The Dallas Water Department reports that, between August 1953 and April 1957, 110,000 acre-feet of Red River water was pumped into the Dallas system. The city further reports that this water contained 150,000 tons of salt (sodium chloride) with concentrations ranging from 800 to 1,400 mg/l. Water department officials have reported various damages caused by the high salt concentration, principally plumbing and hot water tank corrosion and also shrubbery and other vegetation damages, for which many insurance repayments and income tax deductions were claimed. In addition, many users, both by necessity and by choice, obtained drinking water from special sources outside their homes.

Several municipalities, including Oklahoma City, Tulsa, and Wichita Falls, have selected more distant water supply sources because of the unsuitable quality of nearby streams. Tulsa abandoned the Arkansas River as a supply in the 1920's because the highly mineralized water was unsuitable for use. Oklahoma City is now completing a water supply development 100 miles southeast of the city even though two large streams with high salt concentrations lie nearby.

Wichita Falls, Texas, has water and storage rights in the Wichita River at Lake Kemp and can use this water as a supplementary-emergency supply. Because of the high salt content in the Wichita River, however, a reservoir on the Little Wichita River, about 20 miles east of Wichita Falls, has been approved. Denison, Texas, supplements its municipal supply with Red River water from Lake Texoma. During the 1961 and 1962 water years, 698 acre-feet (228 million gallons) of this relatively high dissolved solids water was taken into the Denison raw water system on three occasions.

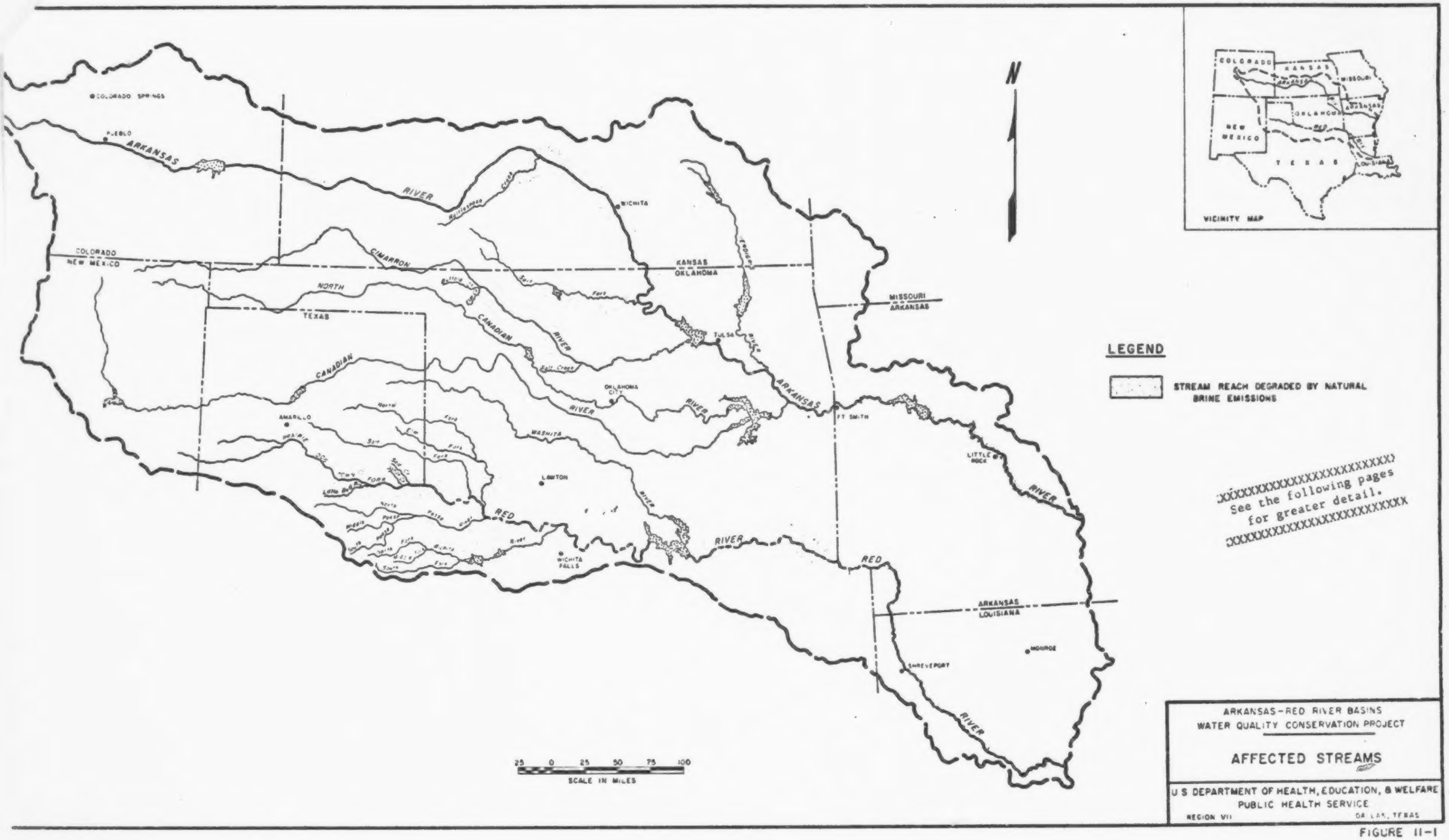
Bossier City, Louisiana, uses the Red River as the only supply of municipal water. For long periods of time during the dry season, there is considerable variation in dissolved solids with concentrations approaching those at Index, Arkansas. An off-channel reservoir with a 6-month capacity has been approved at Bossier City to enable storage of low dissolved solids water for later use.

The salt content of water can be reduced by water treatment processes such as ion exchange and electrodialysis, which are costly and not in common usage, or by pollution control at the source. This study is the first step in the field investigations required to evaluate the problem and to ascertain the feasibility of controlling pollution at its source.

The degradation from natural pollution in portions of the Arkansas-Red River basins is recorded in the diaries of the early explorers of the region. Josiah Gregg, explorer and trader of the 1840's, gives an apt description of the Red River basin when he states "one of the greatest defects of this country (besides the scarcity of water produced by drought) is the great natural scarcity because of the almost absolute lack of constant springs; therefore, even the largest creeks stop running during the dry weather, and the inhabitants are all constrained to the use of water from standing pools which is generally very bad." Other reports of early explorers, dating from the 1700's, tell of salt deposits and plaster of paris accumulations on intermittent streams.

The solid salt accumulation in the Big Salt Plains (Cimarron River) and in the Great Salt Plains (Salt Fork of the Arkansas River) were used as salt sources by the Indians and early settlers for miles around. The area now yields 20 tons of salt a day on a commercial basis.

The 1951 Summary Reports on Water Pollution for the Red and Arkansas Rivers (cooperative State-Federal reports) identified salt pollution as a major problem. The problem was further discussed by the Arkansas-White-Red Basins Inter-Agency Committee in 1955. [3] Streams in the study area affected by natural brine emissions are shown in Figure II-1.


VICINITY MAP
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LEGEND
STREAM REACH DEGRADED BY NATURAL BRINE EMISSIONS
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Rattlesnake Creek
WICHITA
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CIMARRON
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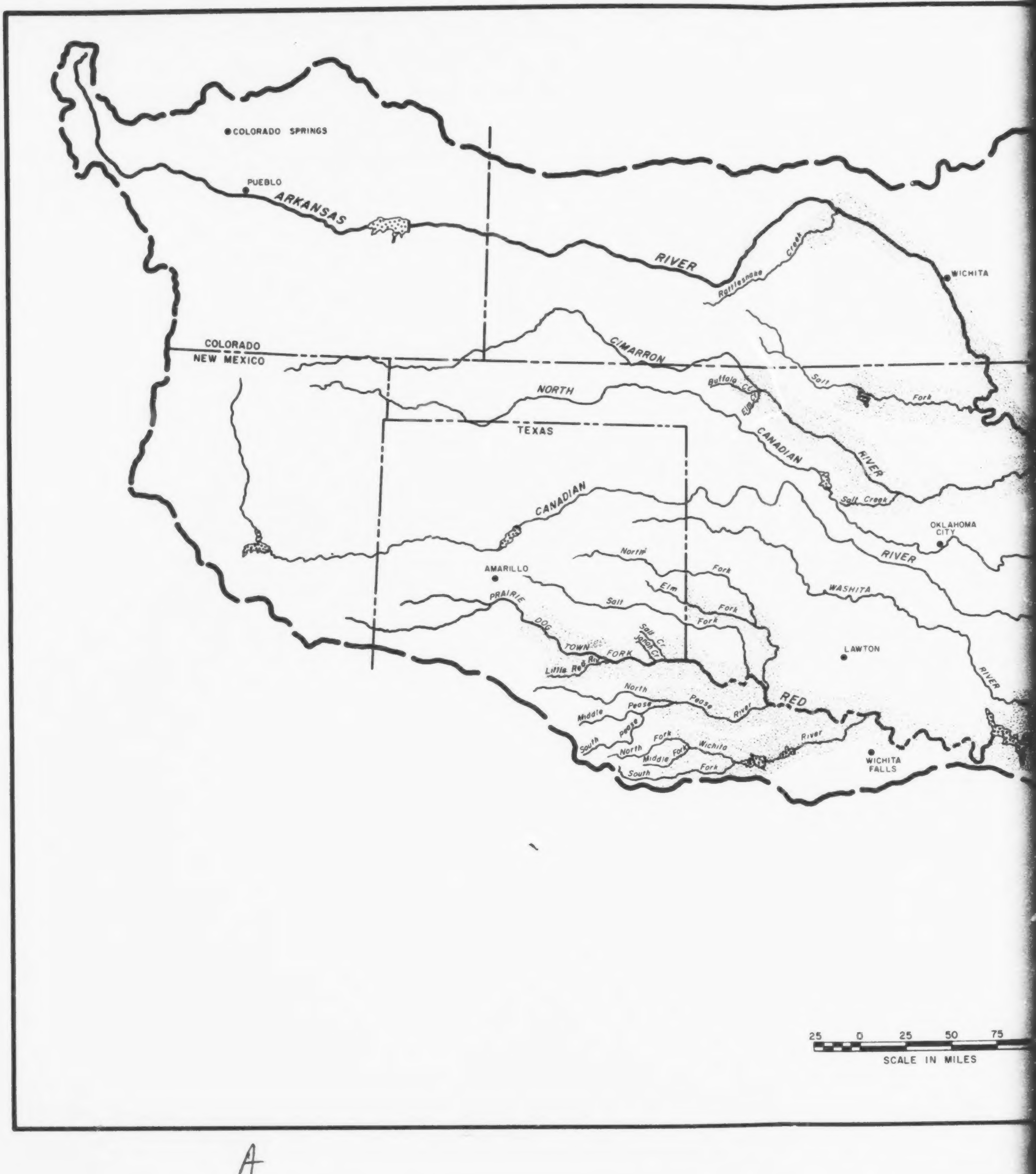
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXX

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

AFFECTED STREAMS

U S DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE II-1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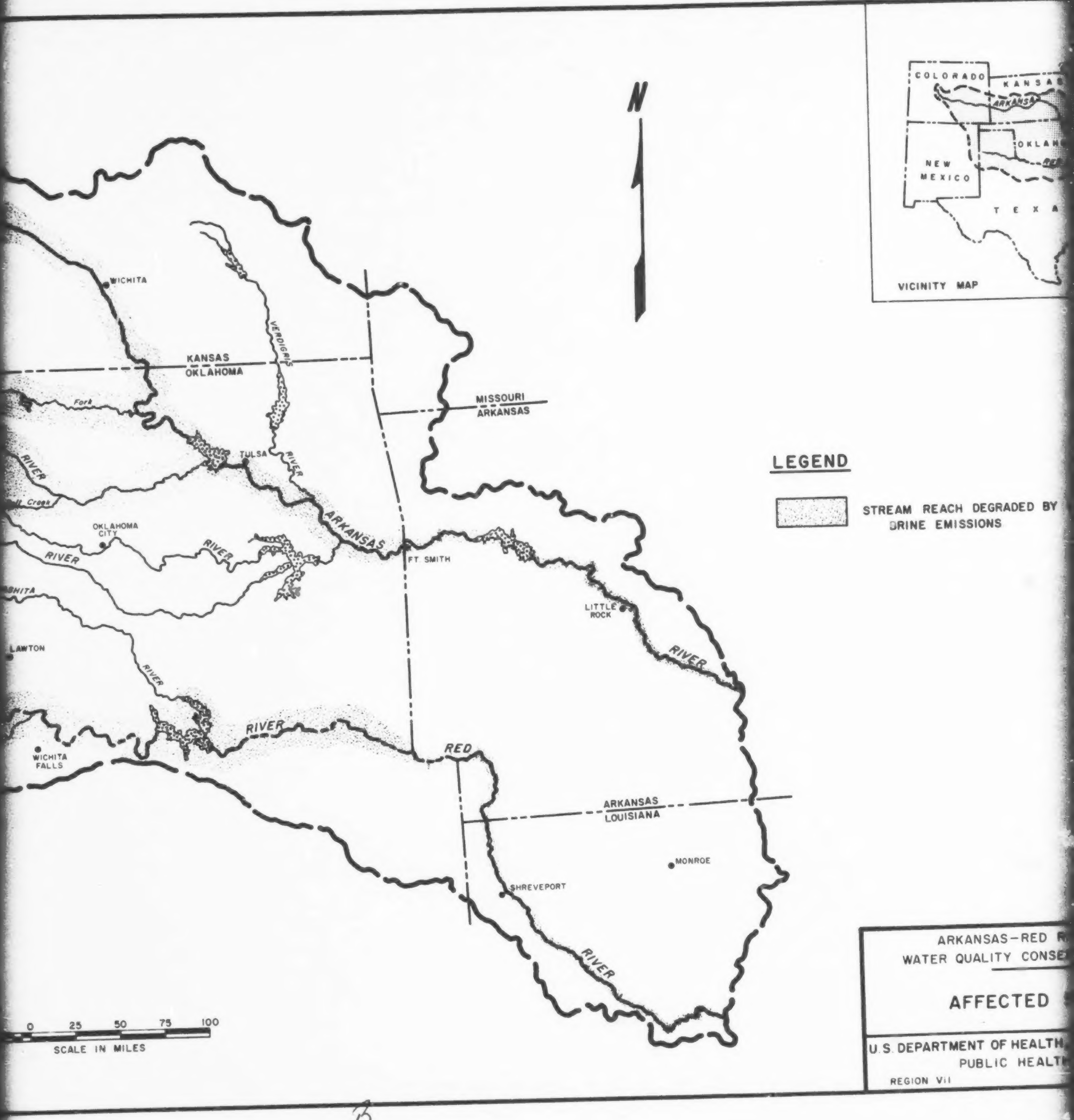
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▨ STREAM REACH DEGRADED BY BRINE EMISSIONS

ARKANSAS-RED R

WATER QUALITY CONSE

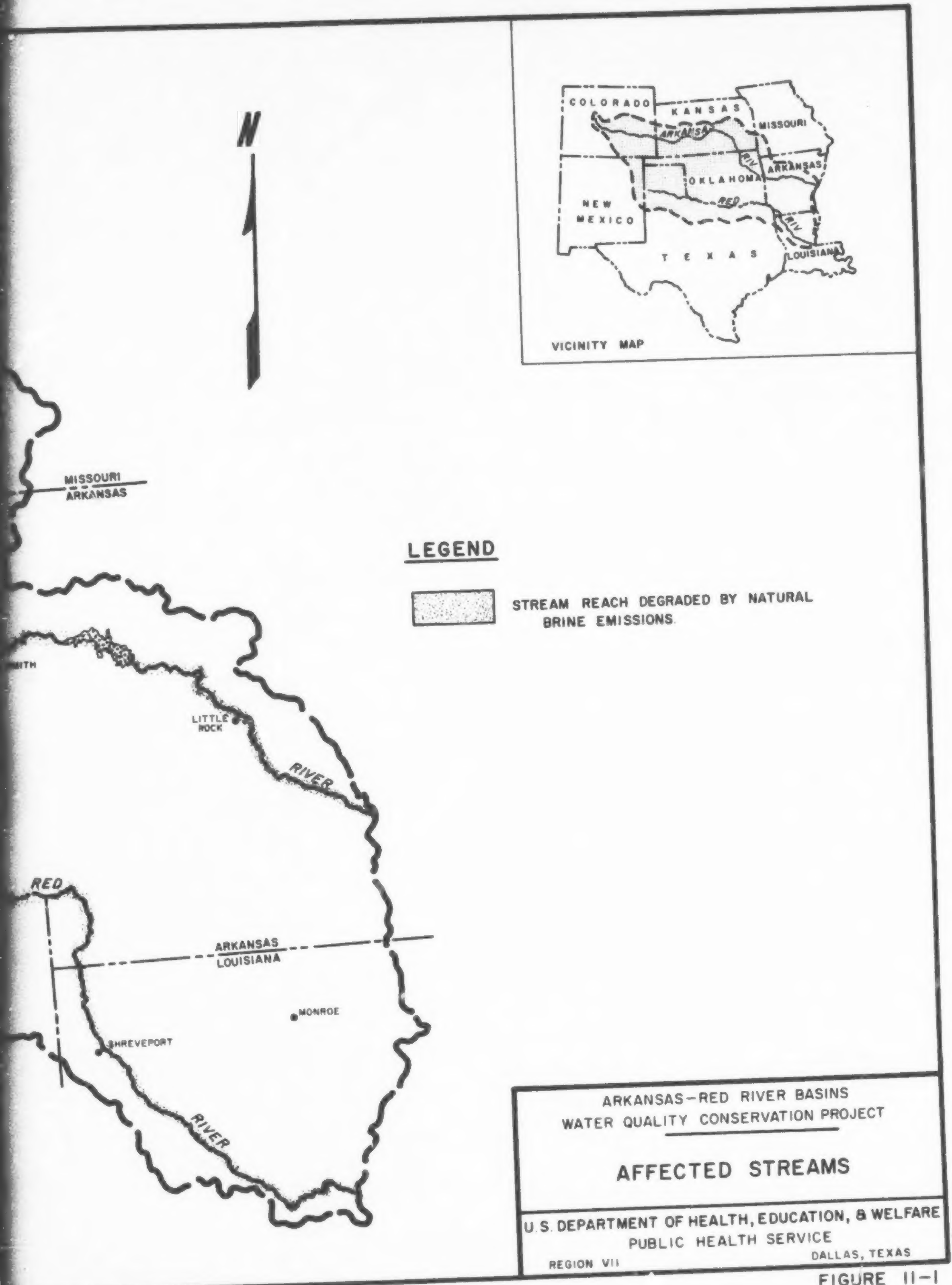
AFFECTED

U.S. DEPARTMENT OF HEALTH,

PUBLIC HEALT

REGION VII

B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STREAM REACH DEGRADED BY NATURAL BRINE EMISSIONS.
MITH
LITTLE ROCK
RIVER
RED
ARKANSAS
LOUISIANA
MONROE
SHREVEPORT
RIVER

ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

AFFECTED STREAMS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE II-1

C

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III. STUDY METHODS

Investigations Before 1957 and Preliminary Work by the Public Health Service

Water degradation by salt has long been recognized as a broad regional and interstate problem. As a result, pertinent water quality studies were made by all States in the area and by various Federal agencies. These have been carried out, both individually and on a cooperative basis, since 1906 and have been related to local water supply and pollution control problems and planning.

Long-term sampling and analyses on the Walnut River by the Kansas State Board of Health [1/] show the effects of increasing oil production both with and without satisfactory brine disposal practices.

In a memorandum report of the late 1940's, the Bureau of Reclamation showed sources of natural salt in the upper Red River basin.

State agencies of Oklahoma and Texas, working along and in cooperation with the Geological Survey, have conducted stream quality and streamflow measurements. [2-4/] The Geological Survey also prepared a report on mineral pollution of the Wichita River, Texas, showing locations and characteristics of natural salt sources. [5/]

These reports served as the basis upon which the Public Health Service evaluated the basin-wide problem and made plans for the continuance of the study. The ensuing reports of June 1958 and January 1959, showed the progress of the study and presented flow data and mineral concentrations for 85 stations in the study area. Table III-1 summarizes the results of some of the longer term stations.

From July 1, 1957 through 1958, the Public Health Service and the Texas State Department of Health conducted a field study of the upper Red River system (with emphasis on the Wichita River) to obtain information on both natural and oilfield brine sources and to develop field investigation techniques.

Table III-1

Summary of Streamflows and Chloride Analyses - 1947-1957

Station Location	PHS Sta. No.	Years of Sampling	Streamflow Averages (cfs) Period Average	Streamflow Averages (cfs) Minimum of Annual Avgs.	Streamflow Averages (cfs) Maximum of Annual Avgs.	Chlorides Average (tons/day) Period Average	Chlorides Average (tons/day) Minimum of Annual Avgs.	Chlorides Average (tons/day) Maximum of Annual Avgs.	Chlorides Weighted Average (mg/l) Period Average	Chlorides Weighted Average (mg/l) Minimum of Annual Avgs.	Chlorides Weighted Average (mg/l) Maximum of Annual Avgs.
Arkansas River Basin											
Arkansas River at Van Buren, Ark.	403	1947-1957	21800	12800	53200	14200	5910	22000	261	105	394
Canadian River near Whitefield, Okla.	392	1947-1957	5710	980	11600	5930	2590	9730	385	134	977
Little River at Sasakwa, Okla.	367	1956-1957	540	50	1030	1970	1110	2820	1350	1020	8200
Canadian River near Bridgeport, Okla.	364	1949-1957	455	75	947	190	83	321	155	89	286
Deep Fork at Beggs, Okla.	390	1952-1957	530	112	1710	139	[illegible]	361	97	45	218
N. Canadian River at Wetumka, Okla.	388	1954-1957	567	157	1560	1100	745	1640	719	177	2070
Verdigris River near Inola, Okla.	283	1948-1957	3770	804	7300	526	98	841	52	41	122
Arkansas River at Tulsa, Okla.	259	1947-1957	7470	1280	15600	11200	3580	19100	555	391	1360
Cimarron River at Mannford, Okla.	258	1950 only	1710	---	---	5660	---	---	1230	---	---
Cimarron River at Perkins, Okla.	253	1953-1957	1160	234	3350	2800	1300	5730	894	633	2470
Arkansas River at Ralston, Okla.	238	1950-1957	4670	772	12800	3400	1130	5970	270	173	945
Salt Fork of Arkansas River at Jet, Okla.	235	1955 only	233	---	---	1780	---	---	2830	---	---
Arkansas River at Arkansas City, Kans.	227	1952-1957	1200	457	2900	880	555	1620	272	145	[illegible]
Red River Basin											
Red River at Denison, Texas	522	1947-1957	5030	1850	11100	3750	1520	7700	276	238	343
Washita River near Durwood, Okla.	520	1951-1957	1320	445	3490	121	58	245	37	26	62
Red River near Gainesville, Texas	508	1953-1957	3270	651	7790	3370	1230	5090	382	280	698
Little Wichita River near Henrietta, Texas	704	1953-1955	72	12	204	14	4	22	722	40	117
Salt Fork of Red River at Mangum, Okla.	481	1947-1948	148	78	219	51	31	72	128	122	149
Red River near Brice, Texas	478	1950-1951	118	66	171	256	219	293	803	616	1220

Source: Public Health Service 6/
Geological Survey 7 8/

Public Health Service Intensive Investigation
1960-1962 Water Years

It appeared that study objectives could best be accomplished by an initial intensive water quality investigation to determine the major salt sources, their characteristics and effects, and to ascertain trends in the release of salt-bearing waste releases. It was determined that observations and special investigations should be continued to represent the complete hydrologic cycle.

Regional office personnel, with the aid and guidance of the Technical Review Committee and Federal, State, and local officials, developed a plan for the intensive study of both basins.

Study Plan

The technical field study was set up as two separate but related and coordinated operations. First, in order to determine in detail the water quality characteristics within the affected area, a network of 64 stream quality (mineral) monitoring stations was established. Mineral loads could be calculated at these significant locations. Stations were located as closely as possible to known natural salt sources to determine their loads and runoff characteristics.

Water Quality Monitoring Network

Some stations monitored streams where the only known salt sources were from man's activities, mainly oil production. In situations where the minerals came from other sources, the amount was determined from available data.

The monitoring network initially consisted of 64 stations -- 37 in the Arkansas River system and 27 in the Red River system. The network was changed during the study to improve efficiency and increase accuracy of the study. At the completion of the intensive 2-year study, 55 mineral quality monitoring stations were in operation.

Streamflow measurements are required for such a study; therefore, wherever possible, the monitoring stations were located at existing streamflow gaging stations. Twenty-five new streamflow gaging stations were established for this study, all of which were installed and operated, under contract, by the Geological Survey, Surface Water Branch. Where possible, these stations were established to serve the needs of other Federal, State, or local agencies. Table III-2 presents monitoring station data on location, period of operation, and station designation as shown on Figure III-1. Complete station location descriptions are given in Volume III of the Appendix.

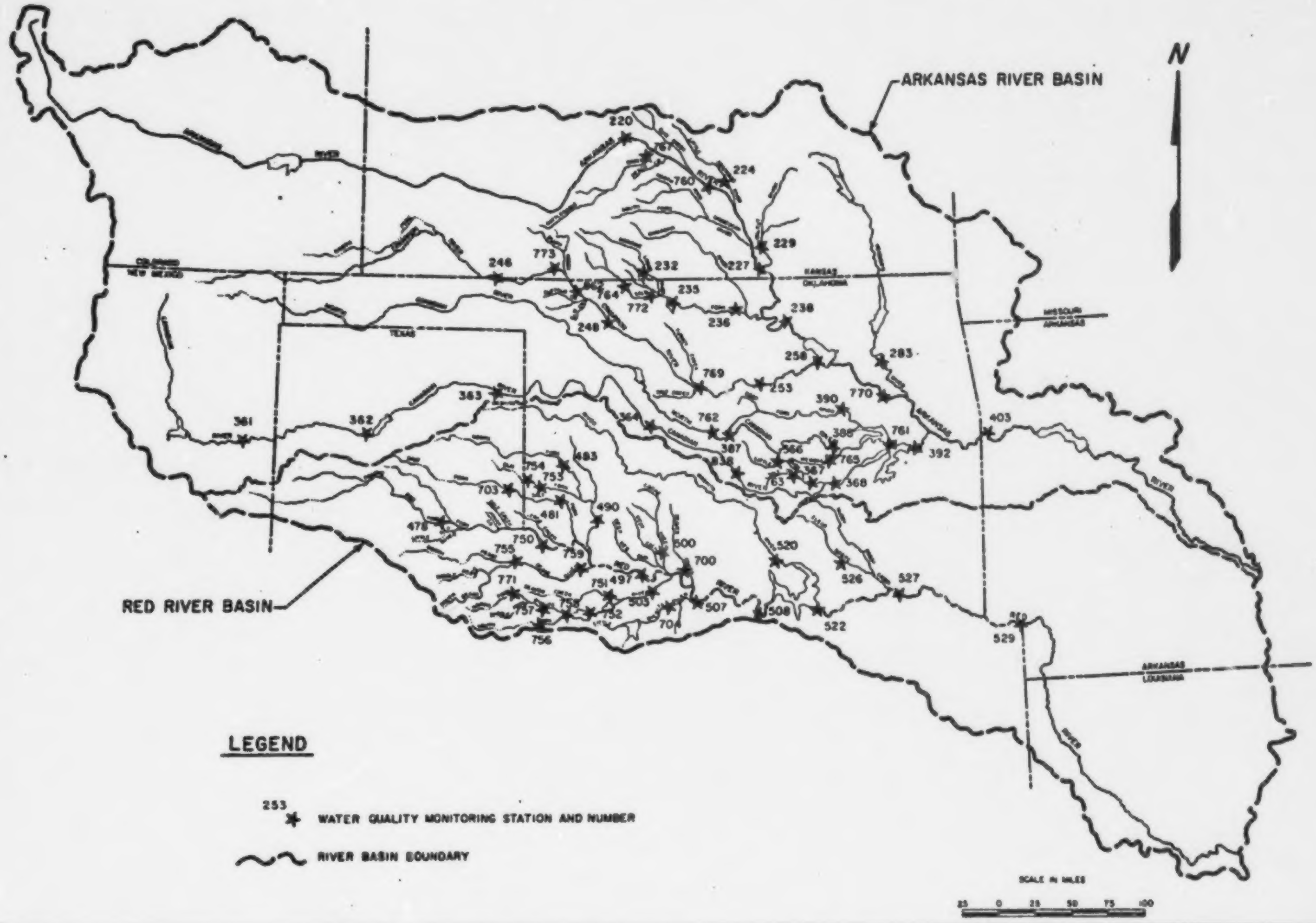
Table III-2

Stream Quality Monitoring Stations

PHS Sta. No.	USGS* Sta. No.	Stream and Location	Period of Quality Monitoring
		Arkansas River	
403	2505.00	Arkansas R. at Van Buren, Ark.	7-1-60 -- 9-30-62
392	2450.00	Canadian R. near Whitefield, Okla.**	7-1-60 -- 9-30-62
368	2315.00	Canadian R. at Calvin, Okla.**	7-1-60 -- 9-30-62
367	2310.00	Little R. near Sasakwa, Okla.	7-1-60 -- 9-30-62
763	2308.00	Salt Cr. of Little R. near DeWright, Okla.	7-1-60 -- 9-20-61
366	2305.00	Little R. near Tecumseh, Okla.	7-1-60 -- 6-5-61
838	2292.00	Canadian R. at Purcell, Okla.	7-1-60 -- 6-5-61
364	2285.00	Canadian R. at Bridgeport, Okla.	7-1-60 -- 9-30-62
363	2280.00	Canadian R. near Canadian, Tex.	7-1-60 -- 9-30-62
362	2275.00	Canadian R. near Amarillo, Tex.	7-1-60 -- 4-3-61
361	2270.00	Canadian R. at Logan, New Mex.	7-1-60 -- 4-4-61
761	2445.00	N. Canadian R. near Eufaula, Okla.	7-1-60 -- 9-30-62
390	2435.00	Deep Fork near Beggs, Okla.**	7-1-60 -- 9-30-62
765	2421.00	Wewoka Cr. near Wetumka, Okla.	7-1-60 -- 9-30-62
388	2420.00	N. Canadian R. near Wetumka, Okla.**	7-1-60 -- 9-30-62
387	2415.00	N. Canadian R. near Okla. City, Okla.	7-1-60 -- 6-6-61
762	2410.00	N. Canadian R. near Okla. City, Okla.	7-1-60 -- 9-30-62
283	1786.00	Verdigris R. near Inola, Okla.**	7-1-60 -- 9-30-62
770	None	Arkansas R. near Haskell, Okla.	6-21-61-- 9-30-62
258	1640.00	Cimarron R. at Mannford, Okla.	7-1-60 -- 9-30-62
253	1610.00	Cimarron R. at Perkins, Okla.	7-1-60 -- 9-30-62
769	1584.00	Salt Cr. of Cimarron R. near Okeene, Okla.	6-8-61 -- 9-30-62
248	1580.00	Cimarron R. near Waynoka, Okla.	7-1-60 -- 9-30-62
862	1579.50	Cimarron R. near Buffalo, Okla.	7-1-60 -- 9-30-62
773	None	Cimarron R. at Protection, Kans.	7-18-61-- 9-30-62
246	1570.00	Cimarron R. near Mocane, Okla.	7-1-60 -- 8-22-62
238	1525.00	Arkansas R. at Ralston, Okla.	7-1-60 -- 9-30-62
236	1510.00	Salt Fork of Arkansas R. at Tonkawa, Okla.	7-1-60 -- 9-30-62
235	1505.00	Salt Fork of Arkansas R. near Jet, Okla.	7-1-60 -- 9-30-62
772	1484.50	Salt Fork of Arkansas R. near Ingersoll, Okla.	6-8-61 -- 9-30-62
764	1483.50	Salt Fork of Arkansas R. near Winchester, Okla.	7-1-60 -- 9-6-61
232	1490.00	Medicine Lodge R. near Kiowa, Kans.	7-1-60 -- 9-30-62
229	1478.00	Walnut R. at Winfield, Kans.	7-1-60 -- 9-30-62
227	1465.00	Arkansas R. at Arkansas City, Kans.	7-1-60 -- 9-30-62
224	1442.00	Little Arkansas R. at Valley Center, Kans.	6-15-61-- 9-30-62
760	1433.30	Arkansas R. near Hutchinson, Kans.	7-19-60 -- 9-30-62
767	1426.20	Rattlesnake Cr. near Raymond, Kans.	7- 1-60 -- 9-30-62
220	1413.00	Arkansas R. at Great Bend, Kans.	7- 1-60 -- 9-30-62
		Red River	
529	3370.00	Red R. at Index, Ark.	7- 1-60 -- 9-30-62
527	3355.00	Red R. at Arthur City, Texas**	7- 1-60 -- 9-30-62
526	3350.00	Clear Boggy Cr. near Caney, Okla.**	7- 1-60 -- 6- 5-61
522	3320.00	Red.R. near Colbert, Okla. (Denison Dam)**	7- 1-60 -- 9-30-62
520	3310.00	Washita R. near Durwood, Okla.	7- 1-60 -- 9-30-62
508	3160.00	Red R. near Gainesville, Texas**	7- 1-60 -- 9-30-62
507	3155.00	Red R. near Terral, Okla.	7- 1-60 -- 9-30-62
704	3150.00	Little Wichita R. near Henrietta, Texas	7- 1-60 -- 9-30-62
700	3135.00	Beaver Cr. near Waurika, Okla.	7- 1-60 -- 6- 5-61
503	3123.00	Wichita R. at Wichita Falls, Texas	7- 1-60 -- 9-30-62
751	3122.00	Beaver Cr. of Wichita R. near Electra, Tex.	7- 1-60 -- 9-30-62
752	3121.00	Wichita R. near Seymour, Texas	7- 1-60 -- 9-30-62
758	3119.00	Wichita R. near Seymour, Texas	7- 1-60 -- 9-30-62
756	3118.00	S. Fork of Wichita R. near Benjamin, Tex.	7- 1-60 -- 9-30-62
757	3117.00	N. Fork of Wichita R. near Truscott, Tex.	7- 1-60 -- 9-30-62
771	3116.00	N. Fork of Wichita R. near Paducah, Tex.	7-28-61 -- 9-30-62
500	3110.00	Cache Cr. near Walters, Okla.	7- 1-60 -- 6- 5-61
497	3085,00	Red R. near Burkburnett, Texas	7- 7-60 -- 9-30-62
759	3082.00	Pease R. near Vernon, Texas	7- 8-60 -- 9-30-62
755	3078.00	Pease R. near Childress, Texas	7- 1-60 -- 9-30-62
490	3050.00	N. Fork of Red R. near Headrick, Okla.	7- 1-60 -- 8- 1-62
753	3034.00	Elm Fork of N. Fork of Red R. near Carl, Okla.	7- 1-60 -- 9-
754	None	Elm Fork of N. Fork of Red R. at Selton Crossing, Okla.	7- 1-60 -- 9-30-62
483	3015.00	N. Fork of Red R. near Carter, Okla.	7- 1-60 -- 7-24-61
481	3005.00	Salt Fork of Red R. at Mangum, Okla.	7- 1-60 -- 9-30-62
703	3000.00	Salt Fork of Red R. near Wellington, Tex.	7- 1-60 -- 7-25-61
750	2995.70	Red R. near Quanah, Texas	7- 1-60 -- 9-30-62
478	2985.00	Prairie Dog Town Fork of Red R. near Brice, Texas	7- 1-60 -- 9-30-62

* Geological Survey Streamflow Gaging Station Number. All Public Health Service Quality Monitoring at same location or nearby.

** Streamflow Gaging Station operated by U.S. Army Corps of Engineers, Tulsa, Oklahoma District. All others by Geological Survey, Surface Water Branch, Kansas District, Oklahoma District, Texas District, Arkansas District, and New Mexico District.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WATER QUALITY MONITORING STATION AND NUMBER
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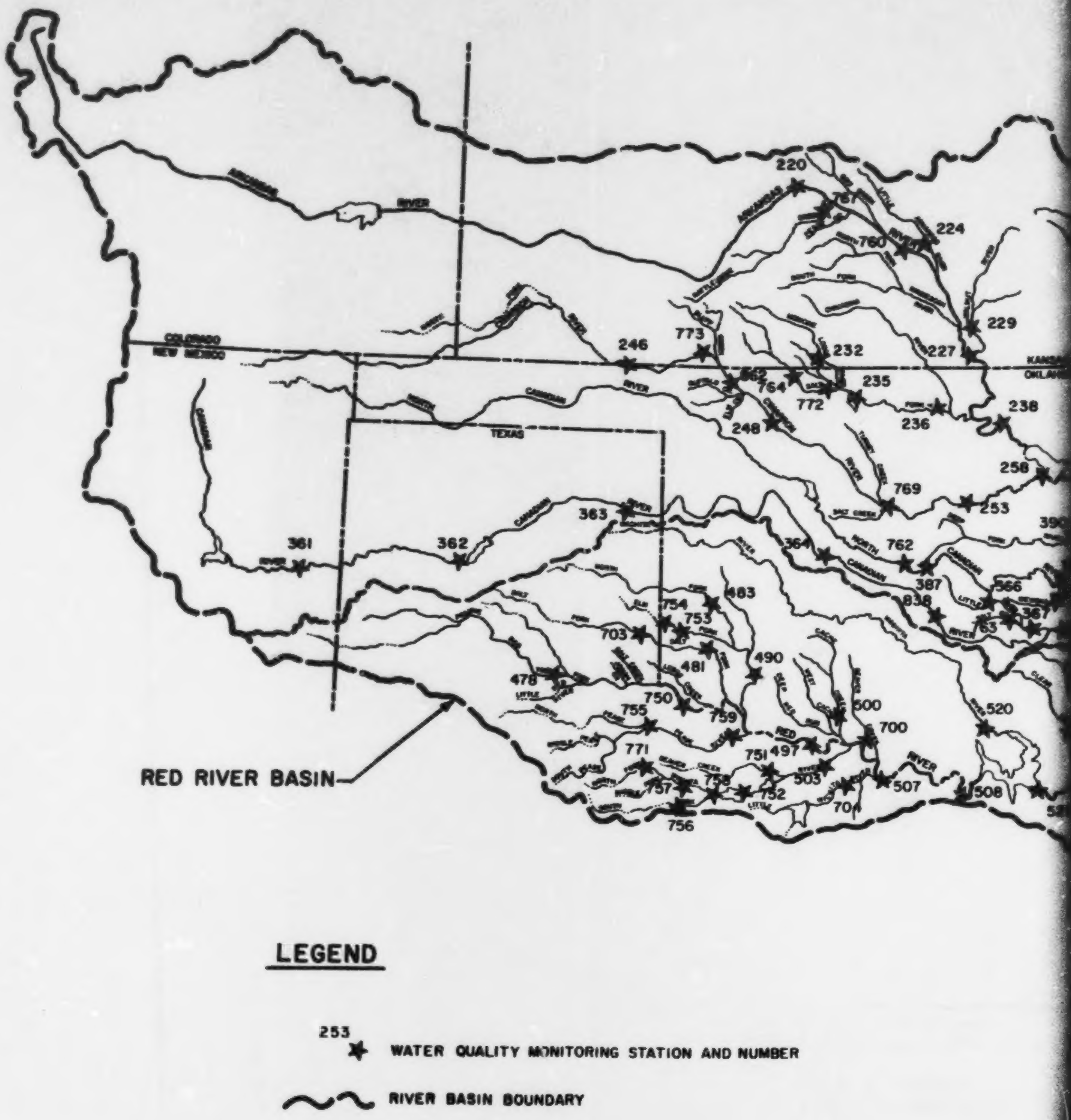
XXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXX

ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

WATER QUALITY
MONITORING STATIONS

U S DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE III-1


ARKANSAS
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NORTH FORK
RED
RIVER
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BEAVER CREEK
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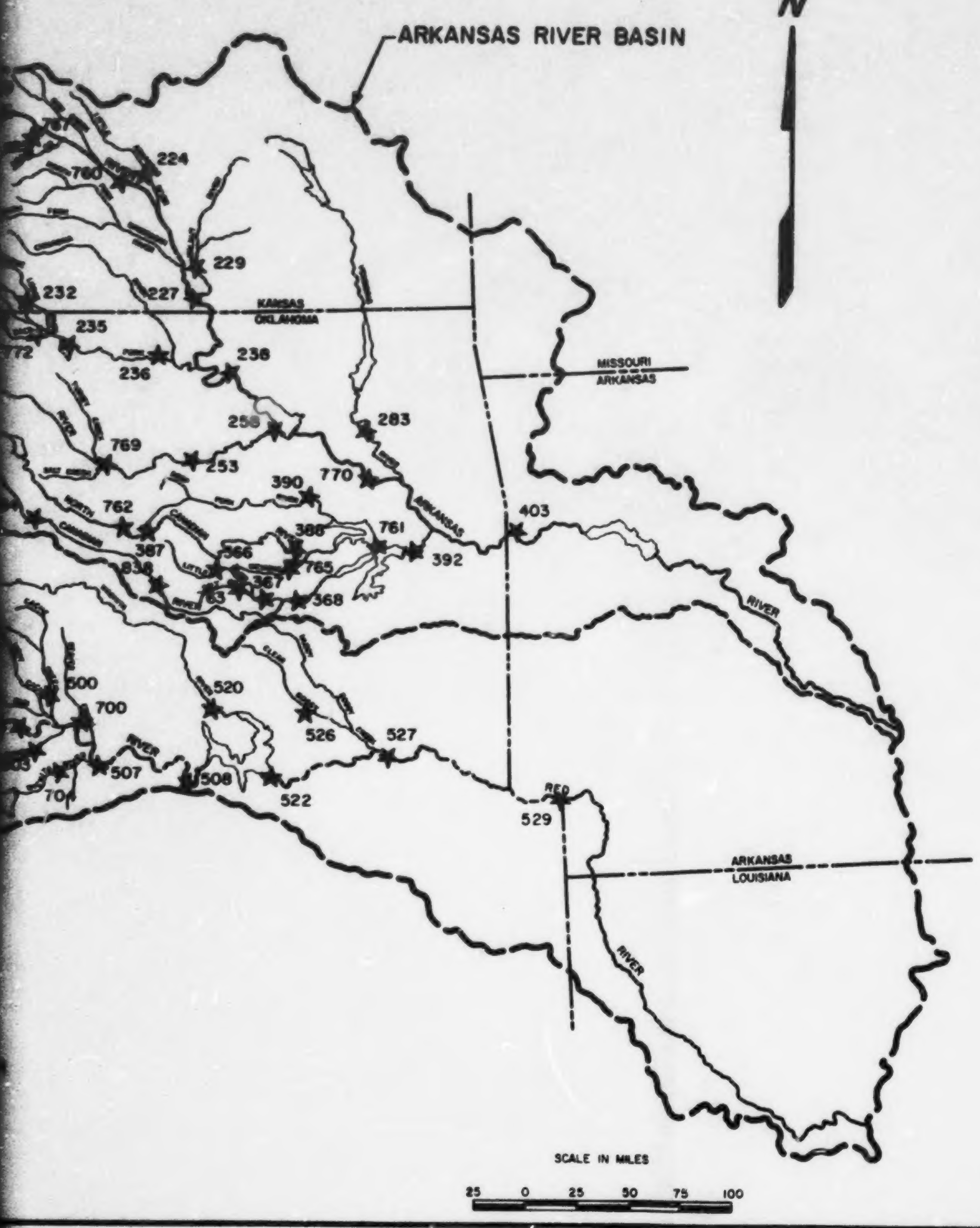
WATER QUALITY MONITORING STATION AND NUMBER
RIVER BASIN BOUNDARY

A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ARKANSAS-RED RIV
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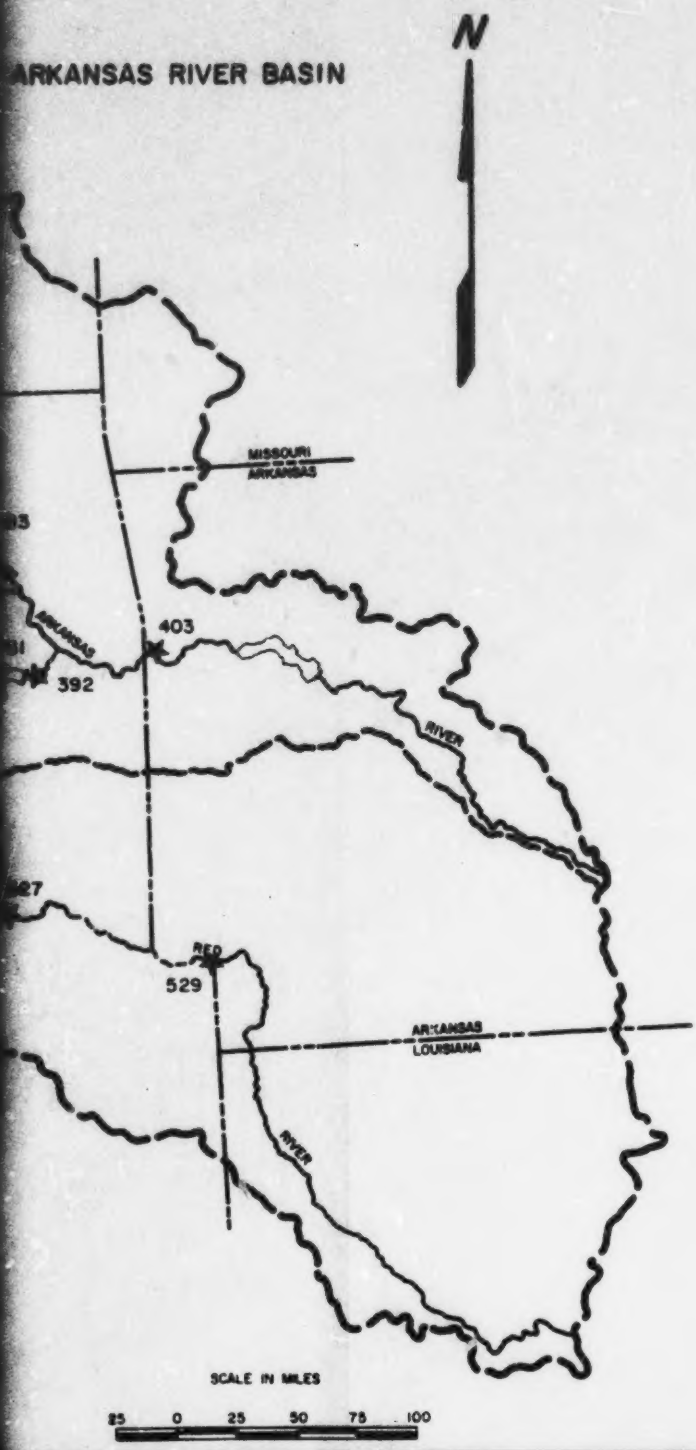
PUBLIC HEALTH
REGION VII

B


ARKANSAS RIVER BASIN
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ARKANSAS
LOUISIANA
RIVER
SCALE IN MILES
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ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

WATER QUALITY MONITORING STATIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII
DALLAS, TEXAS

FIGURE III-1

C

Location of Natural Salt Sources

The second principal activity was the direct investigation of natural salt sources. It was desirable to locate and measure these emissions in such a way as to establish boundaries for the natural brine emission area and quality and flow characteristics of these natural sources.

The identification of natural sources of salt pollution in the Arkansas and Red River basins was accomplished by both aerial and ground reconnaissance surveys, supplemented by information from earlier investigations of State and Federal agencies. Following the identification of salt sources, special field investigations were made at individual source areas, and where conditions warranted, continuous monitoring stations were established to study the characteristics of salt loads in the streams.

Two aerial reconnaissance flights were made over the pollution areas of both river basins. During these flights, the white-colored salt encrustations that result from evaporation of the salt-bearing waters were easily detected. The location of these salt deposits, together with their limits and related surface features, were shown by aerial photographs. These photographs also were used in preparing maps of the salt source areas.

In the ground reconnaissance of the areas, portable conductivity meters were used to detect waters with high salt concentrations. At each point checked, water samples were collected for analysis of salt content in the laboratory. Current meters were used to measure the velocity of the flows. These measurements, when combined with the cross-sectional area for the stream, indicated total flow. The product of salt content and total flow gave the salt load, which was determined for hundreds of streams throughout the river basins before the streams of primary pollution could be specified for intensive field investigations.

Intensive field investigations included the collection of water samples and stream gagings at all readily accessible crossings from the initial point of the survey to the headwaters of the stream. Chloride and sulfate loads were computed from the data and analyzed to determine what segments of the stream, or tributary, required more intensive investigation. Detailed investigations included frequent sampling and gaging and the delineation of source areas which were reinvestigated in their order of relative importance as often as time permitted. Continuous monitoring stations were established to provide continuous flow and specific conductivity (salinity) records wherever warranted and conditions permitted. Other subsurface samplings were made as necessary.

Continuous Measurement of Mineral Quality and Flow

Characterization and definition of the various mineral pollution loads, especially those of natural origin, required continuous measurement of mineral quality. Observation of the typical continuous variations in streamflow quality, and runoff characteristics of the salt sources would enable an evaluation and development of simpler suitable study methods and provide techniques for further necessary study.

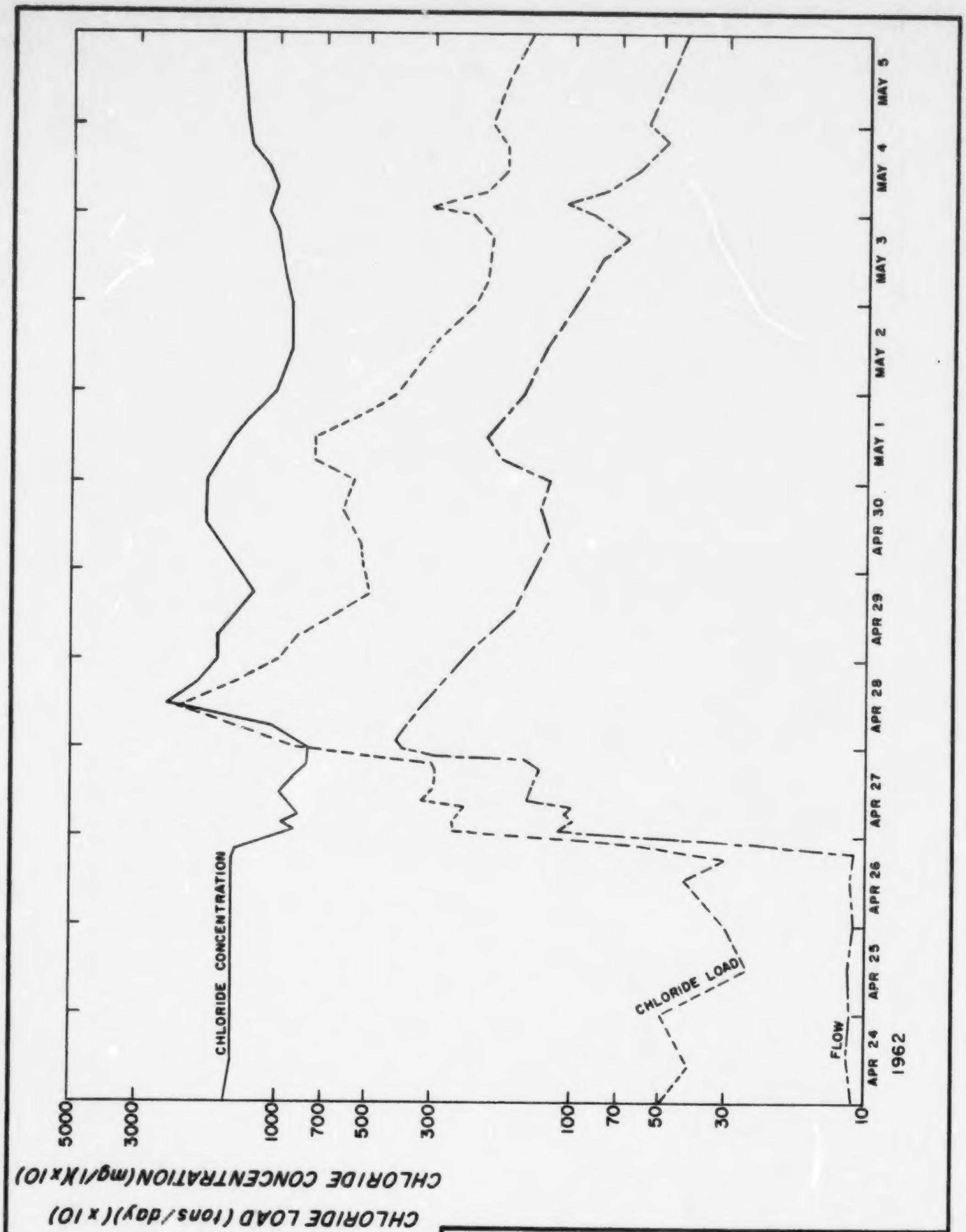
Oilfield brines may be discharged at a relatively constant rate at their source. Similarly, natural brine emissions may be relatively constant in both volume and concentration at points of surface emission. Variations in flow would be expected to occur slowly and not abruptly. At downstream locations, however, the total streamflows and the mineral concentrations fluctuate greatly. Streams in the central and western portions of the basins are intermittent with long periods of no flow and high flows generally occurring for short intervals. The major natural brines and much of the oilfield brine load are contributed from this portion of the basins.

Oilfield brines have a high concentration of dissolved minerals -- mostly salt. During dry periods, those brines which cannot satisfactorily be reinjected are disposed of on the ground, streambed, or disposal pit. Some brine percolates into the moisture-deficient soils and remains there but much of it, due to evaporation, is left as a deposit between its original discharge point and a stream monitoring station.

As shown in Figures III-2 and III-3, high streamflows following a long, dry period will dissolve deposited salts and flush out brine accumulations in a short time. In order to assure adequate representation of these "flushes," continuous quality and flow measurements were essential. Continuous measurement would also serve to identify accidental spills or dumps of brine from industries.

By using continuous sampling procedures, it would be possible to ascertain a correlation between dissolved mineral loadings and flows if it exists. Brine emission patterns could be studied and an extention could be made to periods where flows were measured in the absence of quality data.

A practical field instrument for the direct continuous measurement and recording of chloride, sulfate, and other mineral constituents in streams was not available, but the battery-operated specific (electrical) conductance recorder was selected as a suitable and satisfactory continuous mineral quality monitor. Since the specific



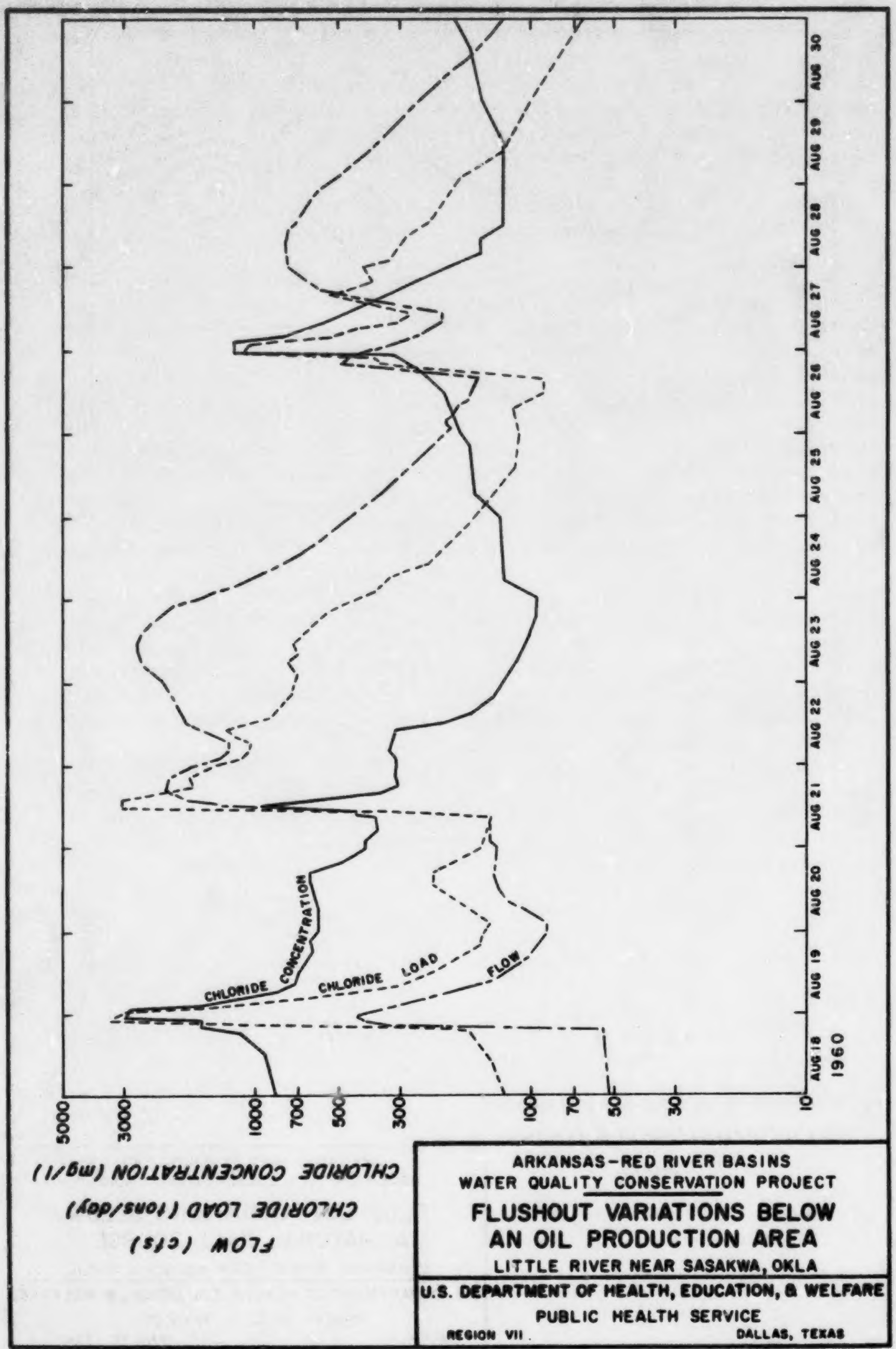
ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

**FLUSHOUT VARIATIONS BELOW
A NATURAL SALT SOURCE**

CIMARRON RIVER NEAR WAYNOKA, OKLA.

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE III-2



ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

FLUSHOUT VARIATIONS BELOW AN OIL PRODUCTION AREA

LITTLE RIVER NEAR SASAKWA, OKLA

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE III-3

conductance of water varies with temperature, field meters used automatic temperature compensators so that the record was always referenced to a standard temperature of 25°C. Because sudden and short-term variations could occur, recorders were installed at all 64 monitoring sites during the late spring and early summer of 1960. Figure III-4 shows the two types of specific conductance recorder installations and the flow gaging stations.

Correlation of Specific Conductance with Dissolved Mineral Concentration

Specific (electrical) conductance is a measure of the ability of water to carry electric current. It is the reciprocal of resistance to current. Distilled or mineral-free water has a conductivity near zero. Waters containing dissolved, dissociated compounds, such as salt or gypsum, will conduct electric current. Sugar is an example of a soluble nondissociating material that does not conduct an electric current. Specific conductance does not indicate certain or special chemical constituent, and different constituents have different unit conductivities. The conductance of natural waters is caused by the presence of several chemicals. There are indefinable, variable factors which make the mathematical relationship of specific conductance to dissolved minerals too inaccurate and unreliable for precise work, such as laboratory research. However, the waters of the middle portions of the Arkansas and Red River basins have relatively high dissolved mineral concentrations with chlorides and sulfates, the dominant constituents. Correlation coefficients (specific conductance with dissolved solids, chlorides, and sulfates) were computed from the results of chemical analyses of grab samples and were sufficiently valid and reliable for field study usage. These correlations are of comparable quality and accuracy to other field measurements of the project and suitable for water resource project design.

The chloride and sulfate ions were selected as the two dominant negative ions in these waters. Both are stable and can be used best for determination of the mineral pollution loads and balances.

Computation of Results

Computation of mineral loads, using continuous specific conductance measurements, required continuous streamflow records (or hydrographs) at each quality station. The Arkansas, Kansas, New Mexico, Oklahoma, and Texas District offices of the Geological Survey, Surface Water Branch, and the U.S. Army Corps of Engineers, Tulsa District, provided subdivided daily streamflow reports for each station so that hydrographs could be produced.

Correlation equations for conversion of specific conductance to concentrations of dissolved solids, chlorides, and sulfates were computed for each station from the chemical analyses of weekly grab samples. Four equations were derived from the data.

(1) Linear
(2) Linear passing through origin
(3) Semi-logarithmic
(4) Logarithmic

Specific conductance charts (7 day) were read by field station engineers and, where necessary and possible, corrections were made. Specific conductance readings and flows were transcribed to punch cards and after accumulation of sufficient data, computations of mineral loads, weighted average concentrations (according to flow), and other results were made by a Honeywell 400 computer at the Public Health Service, Robert A. Taft Sanitary Engineering Center, Cincinnati, Ohio. All computer programing and related work were done by the technical staff of the Public Health Service.

Accuracy of Results

The overall accuracy of the streamflow measurements varied from station to station. In general, the flow of intermittent, broad bed streams in the western and central portions of the basins was measured with fair to poor accuracy by Geological Survey classification. Nearly half of the stations were good, and overall results are of sufficient accuracy for the planning and design which may result from this report.

Specific conductance can be measured within an accuracy of 5 percent; but mechanical failures, electrode fouling, and other similar interferences occur in continuous recording by unattended instruments. The recorder was a battery-operated instrument with a spring-wound clock, chart-drive. The recorders were checked once a week. Accuracy was determined by comparison with measurements made by a portable meter and electrodes, which were checked and standardized at the field station laboratories. Standard brines were prepared by personnel of the Sanitary Engineering Center, Cincinnati, Ohio.

During the 2-year study, continuous records of the conductance at all stations were obtained about 90 percent of the time. The overall accuracy of these measurements for all stations appears to be within 10 percent of the actual conductance. For periods when the recorders were inoperable, adjustments were made for either prolonged periods or for significantly large flows. These adjustments were made only

RECORDER HOUSED IN 10-GAGE METAL BOX.

USGS GAGE HOUSE.

ELECTRODES IN PLASTIC (POLYETHYLENE) PIPE. THIS FLEXIBLE PIPE IS SUSPENDED FROM BRIDGE RAIL AND CAN BE MOVED EASILY TO KEEP THE ELECTRODES SUBMERGED AS THE STREAMFLOW CHANNEL SHIFTS.

RECORDER IN USGS GAGE HOUSE

FLEXIBLE PLASTIC PIPE HOUSING ELECTRODES BETWEEN PIER AND GAGE HOUSE. MOVING OF RECORDER AND ELECTRODES IS NOT REQUIRED BECAUSE OF PERMANENT DEEP POOL AT BRIDGE.

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

TYPICAL WATER QUALITY MONITORING STATIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE III-4

when an average daily specific conductance could be estimated with a high degree of confidence. Methods used to estimate average daily conductances, using the flow hydrographs, included any or all of the following.

1. Results of analyses of grab samples collected by the Public Health Service cooperator (contractor), who inspected the station and cleaned the conductance electrodes, or by the Geological Survey. In some cases, no analyses were available; in others, they were available daily.
2. Review of the specific conductance chart.
3. Simulation of conductivity from a similar pattern of flow and measured conductance.
4. Comparison and balancing of upstream and downstream station loads.

Some adjacent stations were essentially equal, and others could be computed or balanced by adding component loads. Load and flow computations and tabulations were available on daily, weekly, and monthly bases to facilitate these balances.

The overall accuracy in computing mineral loads and concentrations varied from station to station. It appears that this accuracy was poor in the upper reaches of the basins where flows were low and erratic, and improved as flows became more stable downstream. At these downstream locations, accuracy is believed to be within 5 percent of actual.

As a group, the total (measured and adjusted) data and the dissolved solids computed loads and concentrations are believed to be within 10 percent of actual, and the sulfate within 20 percent.

Details for individual stations are given in Volume III of the Appendix.

Other Analyses

Weekly grab samples, obtained by field station personnel, were analyzed at field station laboratories for specific conductance, chlorides, and sulfates. These results were the main source of data for computation of the correlations between conductance and the constituents.

More complete mineral analyses were made on monthly samples from each station (up to 24 samples), including several analyses for trace metallic elements and radioactivity. These analyses were made by the Public Health Service, Water Supply and Pollution Control Division, Basic Data Section, and the Sanitary Engineering Center, Cincinnati, Ohio, and by the Geological Survey, Quality Water Branch, Oklahoma City, Oklahoma District. Basic Data Section personnel also provided guidance and consultation on laboratory operations and procedures and provided standard chemical solutions.

Water analyses were made by procedures given in "Standard Methods for the Analyses of Water and Wastewater," 11th edition, 1960. Sulfates were determined by a turbidimetric procedure which was modified by using a commercial emulsifier found suitable by tests at the Sanitary Engineering Center.

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IV. RESULTS OF FIELD STUDY

Stream Quality

Primary findings of the 2-year intensive field study are related to the objectives of the "Arkansas-Red River Basins Water Quality Control" project--To locate and define the significant natural and manmade sources of salt (mineral) pollution and to determine the effects of these sources on quality of water in the receiving streams. Stream water quality monitoring accomplished the latter objective and aided in the achievement of the former.

The results of the stream quality monitoring program are presented in Volume III of this Appendix.

Weighted values shown in the summary report are based upon a time, flow, and continuously recorded specific conductance relationship. Through the use of correlation equations (described in Chapter III), derived from laboratory analyses of weekly grab samples, and weighted average specific conductance, average mineral concentrations (in mg/1) were computed.

Table IV-1 summarizes the findings presented in Volume III of this Appendix.

Natural Salt Sources

Geologic Origin and Occurrence of Salt Deposits

All of the saline or salt-producing rocks in the Arkansas and Red River basins are of Permian age. They are the marine deposits of 250 million years ago. At the time of their deposition, a salt-water sea extended over the area that now comprises parts of western Texas, southeastern New Mexico, western Oklahoma, and southern Kansas. Some of the sediments accumulated in deep basins that were separated by relatively shallow platforms. Others accumulated on the floors of subsiding bays, lagoons, and shallow inland seas. To the southwest, in the Permian basin of Trans-Pecos Texas and southeastern New Mexico, the rock sequences reached thicknesses of more than 12,000 feet. Of these, 7,500 feet are of marine origin.

Environment of Deposition

All of the sediments were deposited under arid climatic conditions--the salt sequences of gypsum, anhydrite, and halite (rock salt) being produced by the chemical precipitation of salts from the sea water as evaporation increased the salt content of the water to the saturation point. Some basins of accumulation were fed

Table IV-1

Summary of Arkansas and Red River Basins Quality Data
(Weighted Averages for Water Years 1961 & 1962)

PHS Sta. No.	Stream and Location	Mean Flow (cfs)	Concentration (mg/l) Chlorides	Concentration (mg/l) Sulfates	Concentration (mg/l) Dis. Solids	Load (tons/day) Chlorides	Load (tons/day) Sulfates	Load (tons/day) Dis. Solids
	Arkansas River Basin							
403	Arkansas R. at Van Buren, Ark.	38800	107	56	380	11210	5870	39800
392	Canadian R. near Whitefield, Okla.	4520	133	56	402	1620	682	4900
348	Canadian R. at Calvin, Okla.	1380	200	108	649	747	403	2420
367	Little R. near Sasakwa, Okla.	245	442	28	843	291	18	556
763*	Salt Cr. of Little R. near DeWright, Okla.	108	777	18	1270	227	5	371
366*	Little R. near Tecumseh, Okla.	104	83	27	332	23	8	93
838*	Canadian R. at Purcell, Okla.	659	194	275	857	347	492	1530
364	Canadian R. at Bridgeport, Okla.	481	106	356	879	138	462	1140
363	Canadian R. near Canadian, Texas	264	269	184	830	197	132	639
362*	Canadian R. near Amarillo, Texas	279	168	218	762	128	166	579
361*	Canadian R. at Logan, New Mex.	170	80	174	571	36	79	260
761	N. Canadian R. near Eufaula, Okla.	1870	159	40	444	801	201	2240
390	Deep Fork near Beggs, Okla.	715	120	28	315	231	54	607
765	Wewoka Cr. near Wetumka, Okla.	151	481	24	811	196	10	331
388	N. Canadian R. near Wetumka, Okla.	525	237	79	646	335	112	913
387*	N. Canadian R. near Okla. City, Okla.	268	261	207	806	189	150	583
762	N. Canadian R. near Okla. City, Okla.	169	123	170	612	56	77	277
283	Verdigris R. near Inola, Okla.	7470	50	37	218	1010	745	4390
770*	Arkansas R. near Haskell, Okla.	10020	311	110	770	8390	2970	20780
259*	Arkansas River at Tulsa, Okla.	8912	309	124	773	7470	3000	18700
258	Cimarron R. at Mannford, Okla.	1880	834	202	1800	4220	1020	9100
253	Cimarron R. at Perkins, Okla.	1410	1060	254	2240	4020	963	8470
769*	Salt Cr. of Cimarron R. near Okeene, Okla.	43	1870	730	4440	219	85	519
248	Cimarron R. near Waynoka, Okla.	274	5110	572	8970	3760	421	6600
862	Cimarron R. near Buffalo, Okla.	160	1960	222	3820	842	95	1640
773*	Cimarron R. at Protection, Kans.	185	441	161	1010	219	80	501
246*	Cimarron R. near Mocane, Okla.	81	561	172	1260	123	38	276
238	Arkansas R. at Ralston, Okla.	7210	174	97	563	3380	1880	10900
236	Salt Fork of Arkansas R. at Tonkawa, Okla.	820	738	233	1630	1630	515	3610
235	Salt Fork of Arkansas R. near Jet, Okla.	363	1460	433	2930	1430	424	2870
772*	Salt Fk. of Arkansas R. near Ingersoll, Okla.	90	131	642	1210	32	155	293
766*	Salt Fk. of Arkansas R. near Winchester, Okla.	96	127	609	1170	33	158	303
232	Medicine Lodge R. near Kiowa, Kans.	103	65	242	600	18	67	167
229	Walnut R. at Winfield, Kans.	1530	67	64	319	276	264	1320
227	Arkansas R. at Arkansas City, Kans.	2600	171	107	564	1200	752	3960
224*	L. Arkansas R. at Valley Center, Kans.	493	34	33	182	45	44	241
760	Arkansas R. near Hutchinson, Kans.	641	286	210	909	494	363	1570
767	Rattlesnake Cr. near Raymond, Kans.	70	1100	137	2020	207	26	379
220	Arkansas R. at Great Bend, Kans.	257	44	316	798	31	219	554
	Red River Basin							
529	Red R. at Index, Ark.	10500	173	126	619	4904	3570	17547
527	Red R. at Arthur City, Texas	7080	256	179	875	4880	3420	16700
526*	Clear Boggy Cr. near Caney, Okla.	337	52	59	252	47	54	230
522	Red R. near Colbert, Okla.	4190	413	284	1270	4670	3210	14300
520	Washita R. near Durwood, Okla.	1240	48	173	571	161	579	1910
508	Red R. near Gainesville, Texas	2820	548	311	1630	4160	2360	12300
507	Red R. near Terral, Okla.	2420	608	351	1809	3956	2284	11769
704	L. Wichita R. near Henrietta, Texas	78	87	19	284	18	4	60
700*	Beaver Cr. near Waurika, Okla.	74	81	133	522	16	27	105
503	Wichita R. at Wichita Falls, Texas	286	664	264	1760	513	204	1360
751	Beaver Cr. of Wichita R. near Electra, Texas	92	314	36	841	78	9	210
752	Wichita R. below Lake Kemp, Texas	169	923	572	2530	423	262	1160
758	Wichita R. near Seymour, Texas	218	814	596	2530	479	350	1490
756	S. Fork of Wichita R. near Benjamin, Texas	54	1340	1050	4110	195	153	600
757	N. Fork of Wichita R. near Truscott, Texas	52	1750	1110	4890	244	155	684
771*	N. Fork of Wichita R. near Paducah, Texas	15	4620	1510	10400	188	61	422
500*	Cache Cr. near Walters, Okla.	146	33	43	273	13	17	108
497	Red R. near Burkburnett, Texas	1290	932	562	2800	3250	1960	9770
759	Pease R. near Vernon, Texas	155	689	617	2312	289	259	971
755	Pease R. near Childress, Texas	89	1612	603	4646	387	145	1116
490	N. Fork of Red R. near Headrick, Okla.	508	480	307	1680	656	420	2290
753	Elm Fk. of N. Fk. of Red R. near Carl, Okla.	54	2300	1340	6070	336	195	886
754	Elm Fk. of N. Fk. of Red R. at Salton Crossing, Okla.	54	588	1240	7930	86	181	426
483*	N. Fork of Red R. near Carter, Okla.	312	182	471	1220	153	395	1020
481	Salt Fork of Red R. at Mangum, Okla.	124	117	624	1360	39	209	457
703*	Salt Fk. of Red R. near Wellington, Texas	127	157	728	1500	54	250	516
750	Red R. near Quanah, Texas	235	2460	1210	6320	1560	770	4010
478	Red R. near Brice, Texas	71	950	909	3160	182	174	606

* Denotes one year or less of quality data.

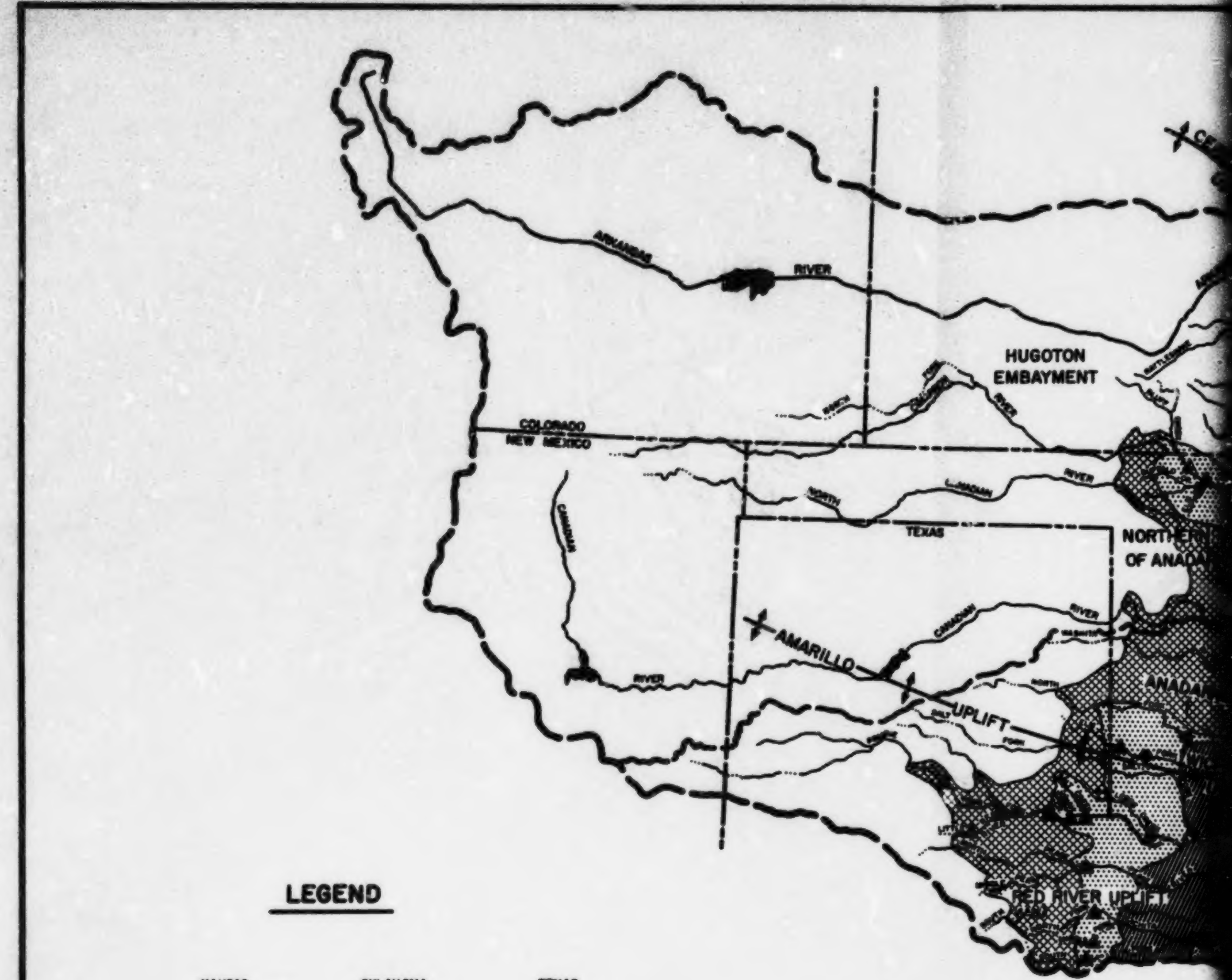
periodically and others continuously with new sea water while evaporation and salt precipitation continued. Great volumes of sea water had to be evaporated over long periods of time to deposit the great thicknesses of salt found today. Evaporation of present day ocean water requires 100 feet of water to deposit 3 feet of salt. It also has been estimated that, if it required 300,000 years to precipitate the salines of the Ochoan series of the Permian, the rate of evaporation over the entire basin must have averaged 9.5 feet per year, which is only about 2 feet less than in the modern Death Valley of California.

Characteristics of Deposition

The formation of evaporites under these conditions accounts for their occurrence in a definite sequence, but overlapping to some extent. Thus, the marine carbonates, limestone and dolomite, may occur along the ancient seaward margin of the sequence, followed by gypsum, anhydrite, and halite (rock salt). Along ancient landward margins, the strata may interfinger with clastic materials to form shales, siltstones, sandstones, and in some areas, red beds--suggesting terrestrial deposition under arid climatic conditions in adjacent land areas. Some of the interfingering deposits give the appearance of braided stream deposits and deposition under deltaic conditions. This accounts for the lenticular or lens-like form of many salt deposits. Small oscillations of sea level created conditions for the alternate deposition of gypsum and anhydrite along with the rock salt.

Deposition in Anadarko Basin

The Permian salt deposits in the Arkansas and Red River basins are closely associated with deposition in the ancient Anadarko basin. The trend of this basin is northwest to southeast with the deepest part adjacent to the Wichita Mountains uplift (Figure IV-1). Rock formations dip toward the axis of the basin where some formations increase greatly in thickness. In the southeastern end of the basin, along its ancient landward margin, the evaporite deposits change to clastic sediments. From the study of well cores and surface exposures, the rocks of the Middle and Upper Permian have been arranged according to their stratigraphic relationships as shown in the accompanying correlation chart (Figure IV-2). It should be noted that essentially the same rock units may be defined differently and assigned different names from one area to another. Description of the individual rock units follow the associated correlation chart (Tables IV-2, IV-3, IV-4, and IV-5).


CE
ARKANSAS
RIVER
HUGOTON
EMBAYMENT
CIMARRON
RIVER
COLORADO
NEW MEXICO
NORTH
CANADIAN
RIVER
TEXAS
NORTHE
OF ANADA
CANADIAN
RIVER
AMARILLO
UPLIFT
CANADIAN
RIVER
WASHITA
NORTH
SALT
FORK
ANADAR
RED RIVER UPLIFT

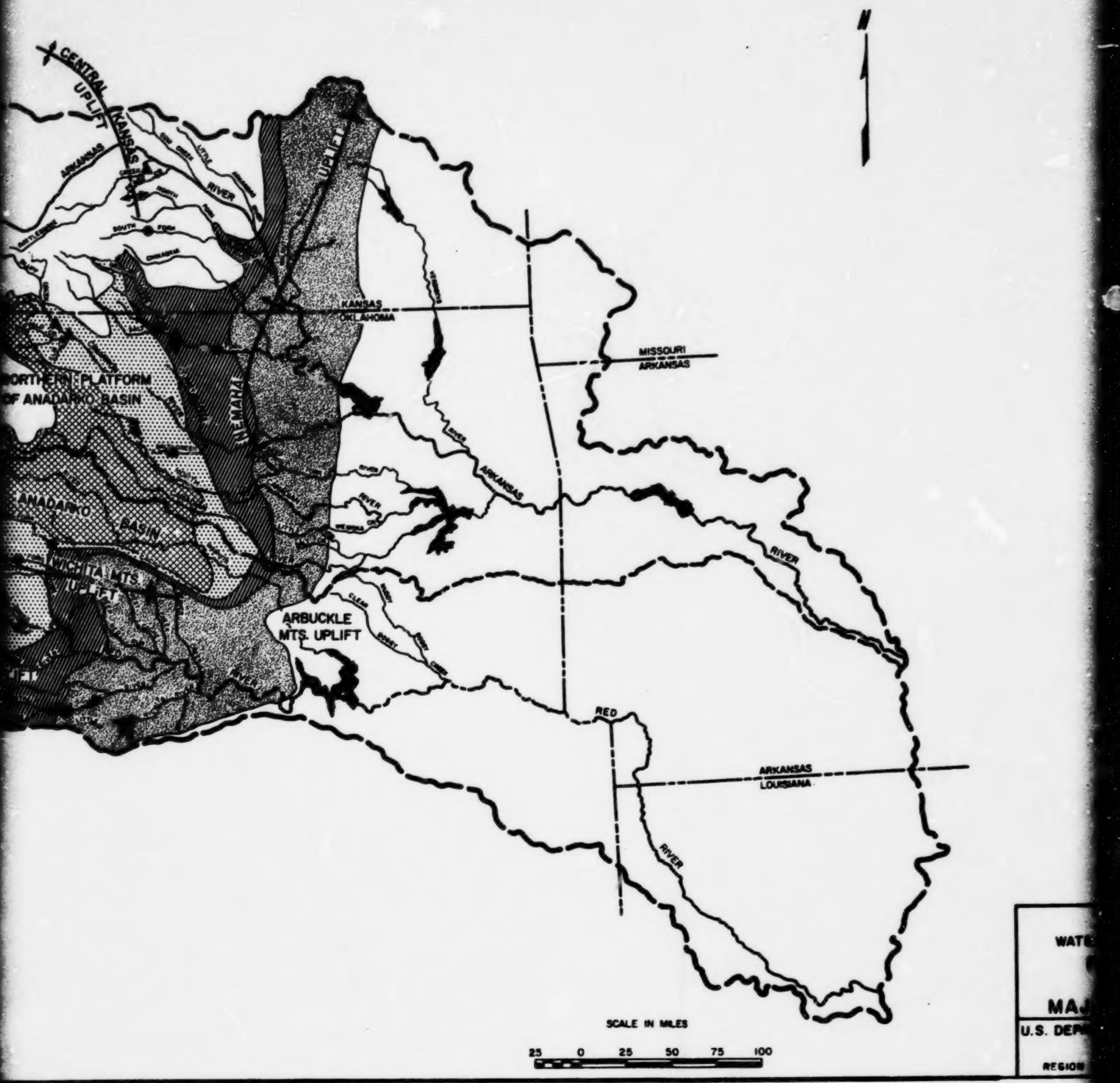
LEGEND

	KANSAS	OKLAHOMA	TEXAS
▦	Taloga Formation Day Creek Dolomite Whitehorse Sandstone	Quartermaster Formation Cloud Chief Formation Whitehorse Group	Quartermaster Formation Cloud Chief Gypsum Whitehorse Sandstone
░	Dog Creek Shale Blaine Formation Flowerpot Shale	Dog Creek Shale Blaine Gypsum Flowerpot Shale (contains Chickasha Formation and Duncan Sandstone in west-central Oklahoma)	Dog Creek Shale Blaine Gypsum Flowerpot Shale San Angelo Sandstone
▨	Cedar Hills Sandstone Salt Plain Formation Harper Sandstone Stone Corral Dolomite	Hennessey Shale (with Cedar Hills Sandstone as upper member)	Clear Fork Group
■	Ninnescah Shale Wellington Formation	Garber Sandstone Wellington Formation	Wichita Group

▲ Major Natural Salt Source ● Other Natural Salt Source

A

769-560 O-63 (Face p. IV-4)


N
CENTRAL KANSAS UPLIFT
ARKANSAS
RIVER
LITTLE
SOUTH FORK
UPLIFT
KANSAS
OKLAHOMA
MISSOURI
ARKANSAS
NORTHERN PLATFORM OF ANADARKO BASIN
NEMAHA
ANADARKO BASIN
WICHITA MTS. UPLIFT
ARBUCKLE MTS. UPLIFT
RIVER
ARKANSAS
RIVER
CLEAR
BOGGY
CREEK
RED
ARKANSAS
LOUISIANA
RIVER
SCALE IN MILES
25 0 25 50 75 100
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MAJ
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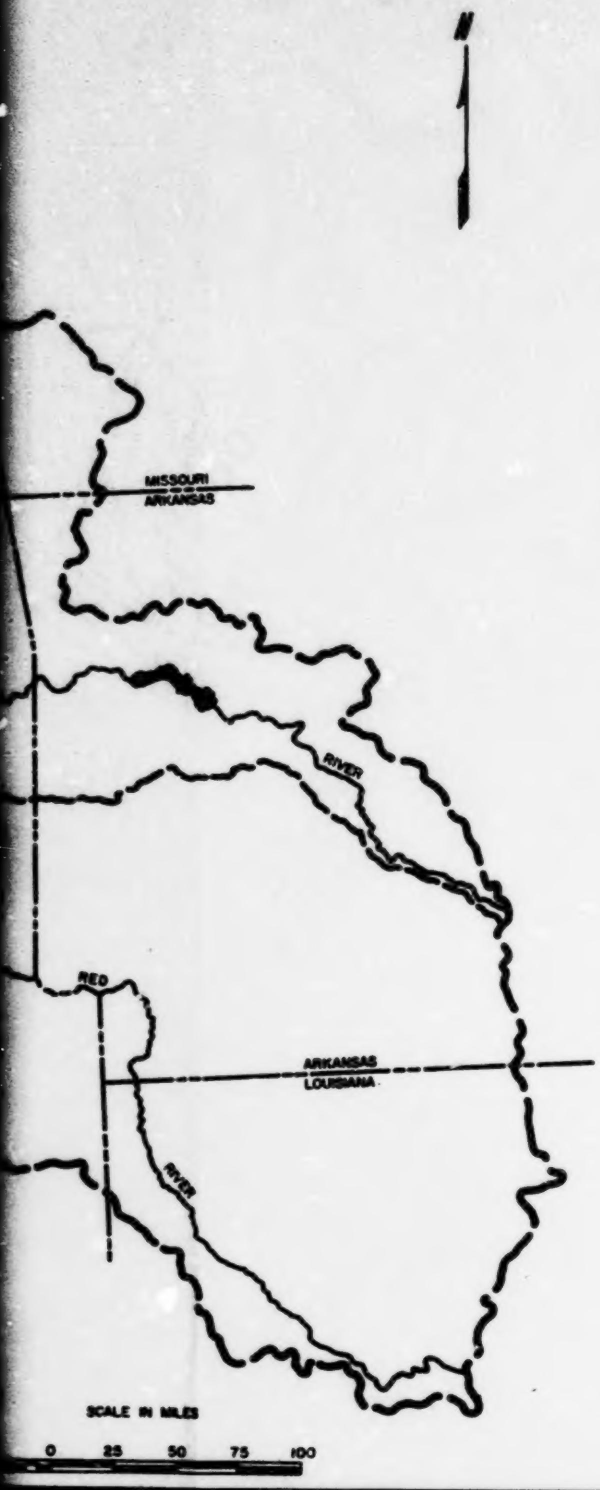
REGION

B


N
MISSOURI
ARKANSAS
RIVER
RED
ARKANSAS
LOUISIANA
RIVER
SCALE IN MILES
0 25 50 75 100

ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

PERMIAN DISTRIBUTION AND MAJOR STRUCTURAL FEATURES

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-1

SOUTHWEST KANSAS		NORTHWEST OKLAHOMA		WESTERN OKLAHOMA		SOUTHWEST OKLAHOMA		NORTHWEST TEXAS		
QUARTERMASTER GROUP	TALOGA FORMATION		CLOUD CHIEF FORMATION		QUARTERMASTER FORMATION		QUARTERMASTER FORMATION	DOUBLE MOUNTAIN GROUP UNIV. of TEXAS BULL. 3232		QUARTER-MASTER FORMATION
	DAY CREEK DOLOMITE				CLOUD CHIEF FORMATION		CLOUD CHIEF FORMATION		WHITEHORSE GROUP	CLOUD CHIEF GYPSUM
	WHITEHORSE SANDSTONE	WHITEHORSE GROUP	RUSH SPRINGS SANDSTONE MARLOW FORMATION	WHITEHORSE GROUP	RUSH SPRINGS SANDSTONE MARLOW FORMATION	WHITEHORSE GROUP	UNDIFFEREN-TIATED			WHITEHORSE SANDSTONE
NIPPEWALLA GROUP	DOG CREEK SHALE	EL RENO GROUP	DOG CREEK SHALE	EL RENO GROUP	CHICKASHA FORMATION	EL RENO GROUP	DOG CREEK SHALE		PEASE RIVER GROUP	DOG CREEK SHALE
	BLAINE FORMATION		BLAINE FORMATION				BLAINE GYPSUM			BLAINE GYPSUM-FLOWERPOT SHALE
	FLOWERPOT SHALE		FLOWERPOT SHALE		DUNCAN SANDSTONE		FLOWERPOT SHALE DUNCAN SANDSTONE			SAN ANGELO SANDSTONE
	CEDAR HILL SANDSTONE		CEDAR HILLS MEMBER OF HENNESSEY SHALE		HENNESSEY SHALE		HENNESSEY SHALE	CLEAR FORK GR.		UNDIFFEREN-TIATED
	SALT PLAIN FORMATION									
	HARPER SANDSTONE									
SUMNER GROUP	STONE CORRAL DOLOMITE									
	NINNESCAH FORMATION		GARBER SANDSTONE		GARBER SANDSTONE		WICHITA FORMATION	WICHITA GR.		UNDIFFEREN-TIATED
	WELLINGTON FORMATION		WELLINGTON FORMATION		WELLINGTON FORMATION					

LOWER — PERMIAN

(Geologic names as used on the U.S. Geological Survey, Geologic Map of Texas, 1937, and Oklahoma, 1954; the Kansas Geological Survey, Map of Kansas, 1937; and various bulletins of the State Geological Survey of Kansas)

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

STRATIGRAPHIC CORRELATION CHART
OCHOAN, GUADALUPEAN, AND LEONARDIAN SERIES
PERMIAN SYSTEM

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-2

Table IV-2

Description of Permian Rock Outcrops in Southeastern Kansas

Subdivision	General Lithology, Salt Occurrence, and Approximate Thickness
Taloga Formation--Day Creek Dolomite, Whitehorse Sandstone	Red, fine-grained sandstone, shale, and siltstone. Few thin, dolomite beds and gypsum stringers. Not known to contain salt in this area. 300 feet thick in Clark and Meade Counties.
Dog Creek Shale	Maroon, silty shale, siltstone, and very fine-grained sandstone. Thin beds of dolomite, dolomitic sandstone, and gypsum. Salt may be present locally in small amounts. 14-53 feet thick in Barber County.
Blaine Formation	Massive beds of gypsum and anhydrite, separated by red gypsiferous shales. Discontinuous thin dolomite beds underlie the gypsum beds. Contains salt locally where deeply buried. 50 feet thick in Barber and Clark Counties.
Flowerpot Shale	Brownish-red, silty, gypsiferous shale and occasional thin, fine-grained sandstone. Characterized by numerous intersecting veins of satin spar and selenite crystals. Salty in many places, and it contains bedded salt in many others, particularly west of Comanche County. 180 feet thick in Barber and Clark Counties.
Cedar Hills Sandstone	Alternating thin beds of red, very fine-grained sandstone, clayey siltstone, and red, silty shale. Beds of sandstone occur locally in upper and lower parts. Contains salt locally. 180 feet thick in Barber and Harper Counties.
Salt Plain Formation	Red, silty, flaky, gypsiferous shale, and some siltstone, and sandstone. Salt occurs in many areas, particularly west of Comanche County. 265 feet thick in Harper County.

Table IV-2 (Continued)

Subdivision	General Lithology, Salt Occurrence, and Approximate Thickness
Harper Sandstone	Red and reddish-brown siltstone, very fine-grained sandstone, and some silty shale. Probably contains salt locally. 220 feet thick in Harper County.
Sumner Group--Stone Corral Dolomite, Ninnescah Shale, Wellington Formation	Upper Part: Mostly brownish-red, silty, blocky dolomitic shale.
	Lower Part: Chiefly gray and green silty shale, and some red shale. Beds of halite make up a significant part of the Wellington formation in the subsurface. The salt-bearing horizon attains a thickness of more than 700 feet in Clark County and 1,200 feet in Ford County.

Source: Kansas Geological Survey 1-12/

Table IV-3

Description of Permian Rock Outcrops in Northwestern Oklahoma

Subdivision	General Lithology, Salt Occurrence, and Approximate Thickness
Cloud Chief Formation	Red, very fine-grained, gypsiferous sandstone and thin interbedded, silty shale. Not known to contain salt in this area. 100 feet thick in Blaine County.
Whitehorse Group--Rush Springs Sandstone, Marlow Formation	Red sandstone, siltstone, and shale, and thin irregular beds of gypsum and dolomite. Not known to contain salt in this area. 200 feet thick in Harper County.
Dog Creek Shale	Predominately red, brown, and green silty, blocky shale and thin dolomite. Locally, shale is dolomitic and sandy. May contain a small amount of salt locally. 190 feet thick in Blaine County.
Blaine Gypsum	Massive, white beds of gypsum interbedded with red and gray gypsiferous shale. Dolomite beds underlie the gypsum beds locally. In some localities, gypsum makes up to 70 percent of the total thickness. Contains salt in this area. 90 feet thick in Woodward County.
Flowerpot Shale	Red, brown, and maroon, silty, blocky, gypsiferous shale, characterized by intersecting veins of satin spar and selenite crystals. Salt occurs in many places. Salt is within 30 feet of the surface locally in Woodward County. Salt water springs issue from the formation in several localities in northwestern Oklahoma. 200 feet thick in Woodward County. Contains Chickasha formation tongue in places.

Table IV-3 (Continued)

Subdivision	General Lithology, Salt Occurrence, and Approximate Thickness
Cedar Hills--Member of Hennessey Shale	Alternating thin beds of reddish-brown silty shale and greenish-gray siltstones. Probably contains salt locally. 100 feet thick in Blaine County.
Garber Sandstone	Predominately reddish-brown shale, and red to brown and light gray siltstone, and very fine-grained sandstone. Contains a small amount of salt in central-western Oklahoma where deeply buried. Thickness not determined.
Wellington Formation	Gray shale with anhydrite and impure dolomites. Contains thick beds of halite in the subsurface. 1,100 feet thick in Alfalfa County.

Source: Oklahoma Geological Survey 13-18/, Geological Survey 19/, and University of Oklahoma 20/

Table IV-4

Description of Permian Rock Outcrops in Southwestern Oklahoma

Subdivision	General Lithology, Salt Occurrence, and Approximate Thickness
Quartermaster Formation	Upper 190 feet is composed chiefly of reddish-brown, fine-grained and medium-grained sandstone and some coarse-grained sandstone and discontinuous beds of siltstone. Lower 160 feet consists of brownish-red shale and thin beds of siltstone. Not known to contain salt in this area. 350 feet thick in Beckham County.
Cloud Chief Formation	Red, fine-grained, gypsiferous sandstone, thin interbedded, silty shale and thin beds of gypsum, anhydrite, and dolomite near the top and bottom. Not known to contain salt in this area. 430 feet thick in Beckham County.
Whitehorse Group	Predominately pink and red, shaly, silty, fine-grained sandstone and siltstone and a few irregular thin beds of gypsum and dolomite. Not known to contain salt in this area. 390 feet thick in Beckham County.
Blaine Gypsum	Massive, white beds of gypsum interbedded with red and gray gypsiferous shale. Dolomite beds underlie the gypsum beds locally. In some localities, gypsum makes up 70 percent of the total thickness. Salt springs issue from the formation in southwest Beckham and southern Jackson Counties. 140 feet thick in Beckham County.
Dog Creek Shale	Predominately red, brown, and green, silty, blocky shale and thin dolomite. Locally shale is dolomitic and sandy. Contains small amount of salt in parts of southwestern Oklahoma. 80 feet thick in Beckham County.

Table IV-4 (Continued)

Subdivision	General Lithology, Salt Occurrence, and Approximate Thickness
Flowerpot Shale	Red, brown, and maroon, silty, blocky, gypsiferous shale, characterized by intersecting veins of satin spar and selenite crystals. Salt occurs within 30 feet of the surface locally in northern Harmon County. Salt springs issue from the formation in several localities in southwestern Oklahoma. 160 feet thick in Beckham County. Partially underlain by Duncan sandstone.
Hennessey Shale	Yellowish-gray, buff, and red, blocky shale, and a few thin, fine-grained, calcareous sandstones. Not known to contain salt in this area. 850 feet thick in central-western Oklahoma.
Wichita Formation	Equivalent to the Garber sandstone and Wellington formation. Generally red-brown shale, siltstone, sandstone, impure limestone, and anhydrite. Contains stringers of salt locally.

Source: Oklahoma Geological Survey 17 18 21/, Geological Survey 19/, University of Oklahoma 20/, Oklahoma Planning and Resources Board 22/, and Geological Congress, XXI Session 23/

Table IV-5

Description of Permian Rock Outcrops in Northwestern Texas

Subdivision	General Lithology, Salt Occurrence, and Approximate Thickness
Quartermaster Formation	Predominately red, thin sandstone and gypsiferous shale. Not known to contain salt in this area. 250 feet thick in Motley County.
Cloud Chief Gypsum	Red, fine-grained sandstone, containing irregular beds of gypsum, thin dolomite, and red shale. May contain salt in the basal part. 300 feet thick in Hall County.
Whitehorse Sandstone	Red, fine-grained sandstone and irregular beds of dolomite and gypsum. Contains thick beds of salt locally, especially to the south and west of Cottle County. Salt springs may issue from near the base locally. 400 feet thick in Hall County.
Dog Creek Shale	Red and brown, silty, blocky, gypsiferous shale and irregular beds of dolomite and gypsum. Contains salt locally in this area. Salt springs issue from the formation in Cottle and King Counties. 280 feet thick in Childress and Hardeman Counties.
Blaine Gypsum--Flowerpot Shale	Red and brown gypsiferous silty shale, massive beds of white and light gray gypsum, and several discontinuous impure beds of dolomite. Contains salt in parts of northwest Texas. Salt water may seep from the rocks locally in this area. May be about 250 feet thick in Hall County.
San Angelo Sandstone	Brown and red-brown, massive sandstone and siltstone, silty shale, and conglomerate. May contain salt locally in this area. 140 feet thick in Foard County.

Table IV-5 (Continued)

Subdivision	General Lithology, Salt Occurrence, and Approximate Thickness
Clear Fork Group	Red, silty, gypsiferous shale, fine-grained sandstone, and irregular, thin beds of dolomite and gypsum. Salt is present locally in this area. 1,200 feet thick in Childress County.
Wichita Group	Anhydrite with gray shale and siltstone dominant in outcrops. May contain a small amount of salt locally. 900 feet thick in Childress County.

Source: Commission of Panhandle Geological Society 24/, Geological Survey 25/, and Geological Society of America 26/

Major Salt Zones

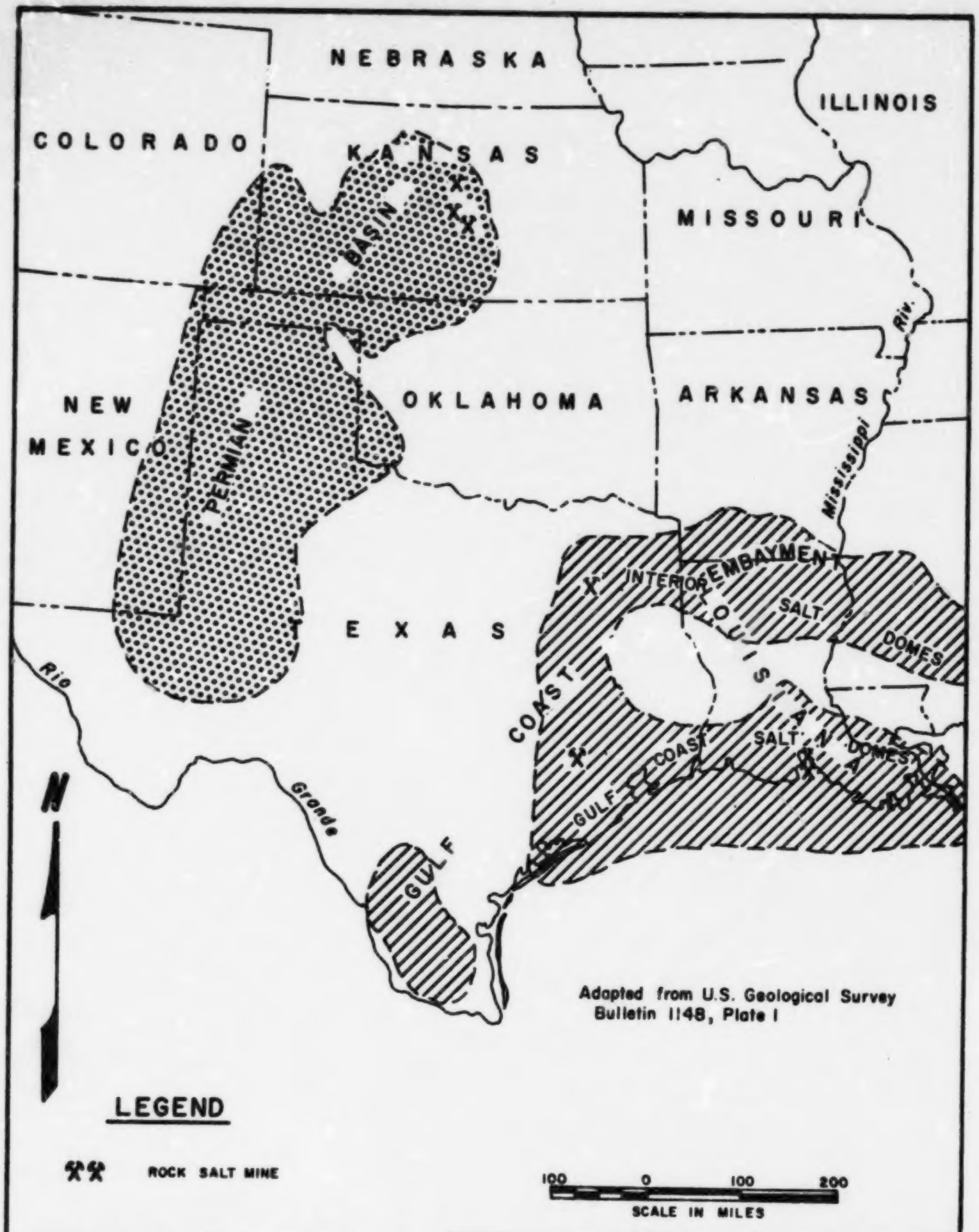
Three distinct salt zones are present in south-central Kansas but are less discernible to the south. The lower or deepest zone contains thick bedded salt that is mined commercially in Kansas. This is the Hutchinson Salt Member of the Wellington Formation. The formation dips rapidly to the south into the Anadarko basin and is generally at too great a depth to influence salt pollution. The middle salt zone is also at a relatively great depth. It is found in the Ninnescah Shale and Stone Corral Dolomite of the Upper Sumner Group in Kansas. The corresponding Garber Sandstone and lower Hennessey Shale contain this salt in northwestern Oklahoma. The upper salt zone is the most widespread throughout the river basins and is believed to supply most of the salt to the salt springs and salt plains. The salt in this zone is not continuous. It occurs from southern Kansas, through western Oklahoma, and into the Texas Panhandle and northern Texas. It is of lens-like nature and found only in patches. This salt has been cored at a depth of only 30 feet at the Big Salt Plains in Oklahoma. In Kansas, this salt zone is found in formations ranging upwards from the Harper Sandstone, through the Cedar Hills Sandstone, Flowerpot Shale, and into the Blaine Formation. In Oklahoma, it is found from the Hennessey Shale upward through the Flowerpot Shale, Blaine Formation, and into the Whitehorse Sandstone. The areal extent of bedded salt is shown on Figures IV-3 and IV-4.

Physiographic Relationships of Salt Deposits and Drainage Features

Source areas of natural salt emission are underlain by Permian rock formations of red shale, siltstone, sandstone, dolomite, dolomitic limestone, and gypsum. The formations which include these rocks also contain the upper, middle, and lower salt zones described above. Broadly defined, the region or belt of natural salt emission occurs along the eastern portion of the High Plains section, and the western part of the Central Lowland, as described under "Description of Basins" (Chapter I).

Nature of Salt and Gypsum Deposits

The salt found in the greater Permian basin is crystalline sodium chloride, with small amounts of sulfate, magnesium, and calcium. The more thickly bedded salt is generally clear and almost free of impurities, whereas the thinner bedded salt generally contains shale partings and may be tinted red or orange, with small quantities of iron. A large percentage of the salt contains so much red clastic material that the salt has a dirty looking, reddish-brown appearance.


NEBRASKA
ILLINOIS
COLORADO
KANSAS
BASIN
MISSOURI
Riv.
NEW MEXICO
PERMIAN
OKLAHOMA
ARKANSAS
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TEXAS
INTERIOR
EMBAYMENT
SALT
DOMES
LOUISIANA
COAST
GULF
COAST
SALT
DOMES
GULF
Rio Grande
N
100 0 100 200
SCALE IN MILES

Adapted from U.S. Geological Survey
Bulletin 1148, Plate I

LEGEND

⚒ ROCK SALT MINE

ROCK SALT DEPOSITS IN SUBSURFACE

▨ PERMIAN OR JURASSIC

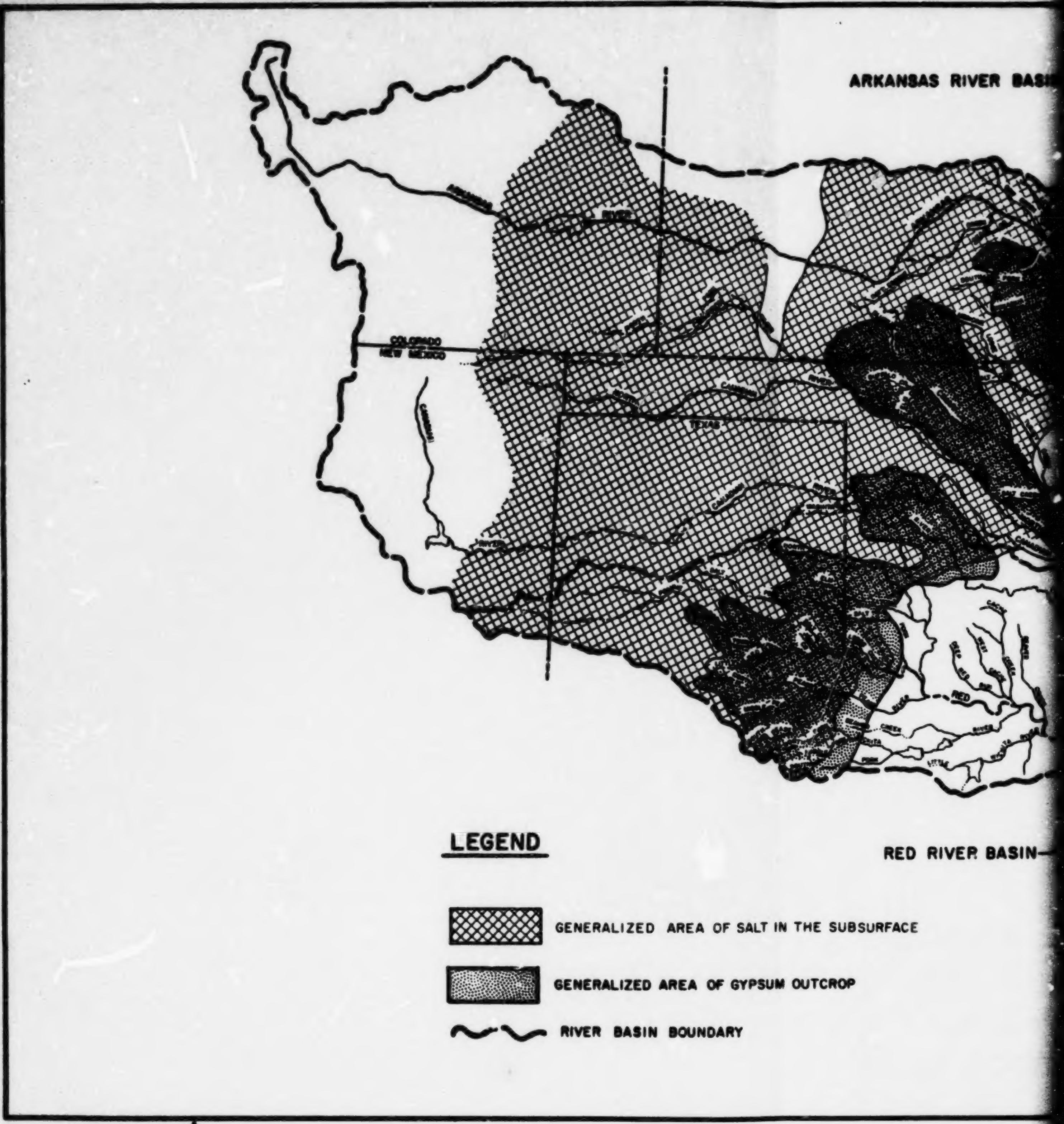
▩ PERMIAN

ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

INDEX MAP OF ROCK SALT DEPOSITS IN
GREATER ARKANSAS AND RED RIVER BASINS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-3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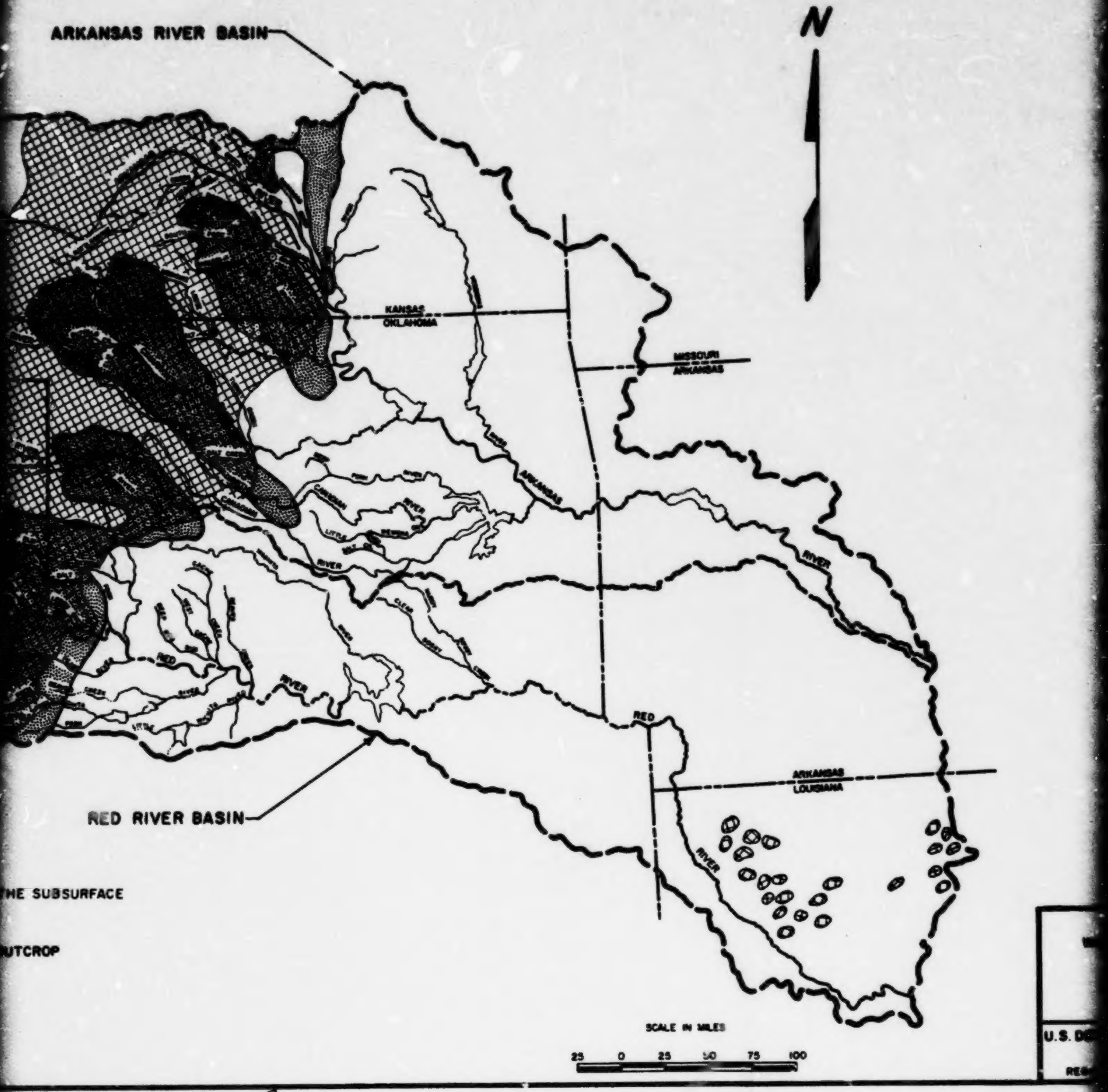
ARKANSAS
RIVER
COLORADO
NEW MEXICO
CANADIAN
TEXAS
RIVER
RED
CREEK
RIVER
RED RIVER BASIN—
LEGEND
GENERALIZED AREA OF SALT IN THE SUBSURFACE
GENERALIZED AREA OF GYPSUM OUTCROP
RIVER BASIN BOUNDARY

A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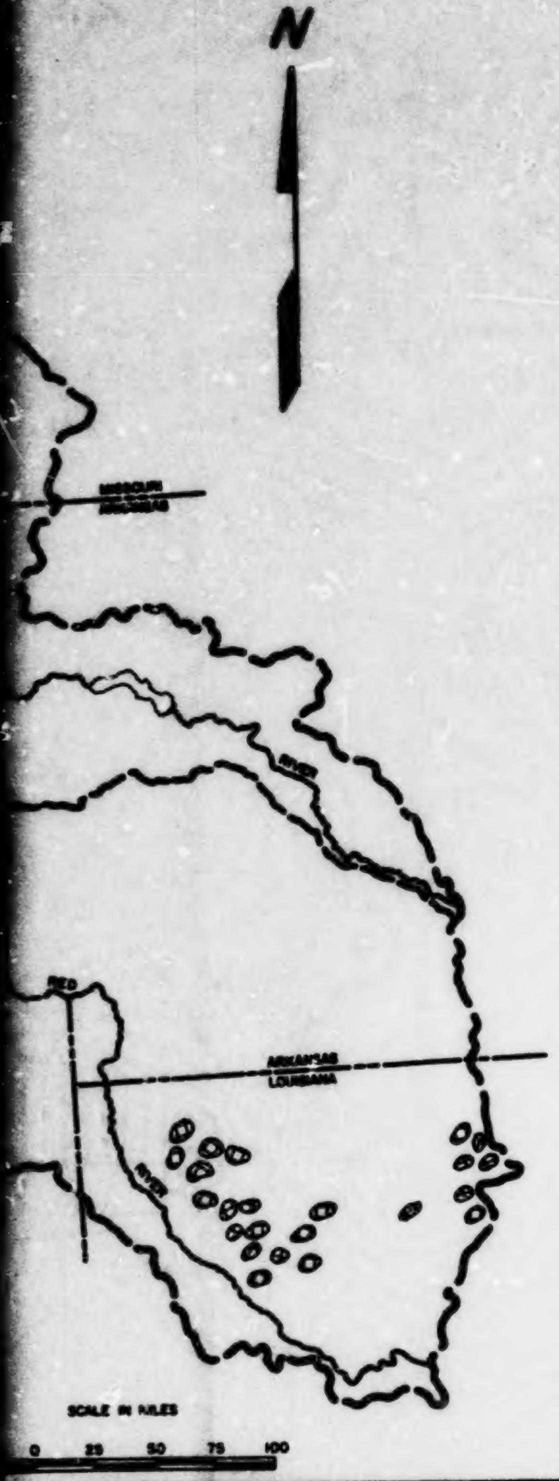
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ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

SALT AND GYPSUM AREAS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

C FIGURE IV–4

Analyses show that the salt mined commercially in central Kansas contains about 96.5 percent sodium chloride, and the remaining 3.5 percent primarily calcium sulfate and magnesium chloride.

Calcium sulfate ($CaSO_4$), in its various forms, is found throughout the region of salt springs and plains in the Arkansas and Red River basins (Figure IV-4). It is an evaporite product, as is halite (NaCl), and, therefore, is found in close association with salt. Types of calcium sulfate found in this area are alabaster, anhydrite, massive gypsum, gypsite, satin spar, and selenite. All of these, with the exception of anhydrite, are different crystalline forms of hydrous calcium sulfate ($CaSO_4.2H_2O$) or gypsum. Anhydrite ($CaSO_4$) is the anhydrous form of calcium sulfate and is found interbedded with, as inclusions in, gypsum. Upon the addition of water (H_2O) to anhydrite, hydration takes place and results in an alteration to one or more of the hydrous calcium sulfate forms. An increase in volume of one-third accompanies this process and may greatly displace the overlying sediments.

The gypsum in these basins is found within the formations of Permian age. Although gypsum is generally found in the subsurface of any area where marine deposition has occurred, only the surface exposures and shallow-bedded gypsums will be considered here as the natural sources of calcium and sulfate pollution of the streams.

In northwestern Texas, southwestern Oklahoma, west-central Oklahoma, and northwestern Oklahoma, the gypsum to be considered ranges upward from the Flowerpot to the Cloud Chief Formation. In north-central Oklahoma and extending northward through central Kansas, the Wellington Formation gypsum is extensively exposed.

Of the numerous formations containing gypsum, only the Blaine and the Wellington have been worked commercially in this region. Of these two, the Blaine is the more important and is the only formation being exploited at this time. In some localities, gypsum makes up 70 percent of the total thickness of the Blaine. Layers of massive gypsum up to 60 feet in thickness have been reported in the Blaine, but generally the workable zones are 10 to 20 feet thick, separated by reddish shales and sandstones.

The relationship of Permian rock salt, gypsum, and associated rocks to drainage characteristics and solution features is given in the following summary.

1. The eastern margin of the buried salt deposits are truncated too abruptly in places to be explained by the depositional processes which produced the beds. The removal of salt by solution would account for the sharp eastern boundary of the salt formations where this feature is known to occur.

2. Salt springs occur within a wide, northeast-trending belt which is the outcrop area of rocks that contain salt in the subsurface farther to the west. The springs occur near the present eastern limit of the salt deposits. As the salt is removed the existing boundary of salt deposits retreats westward. Removal of the salt at different rates has resulted in remnants or patches of salt east of the main body of salt deposits. This feature is especially noticeable in the upper salt zone in northwestern Oklahoma.

3. Surface features that result from solution include collapsed, slumped, and distorted rock strata and sinkholes. All are present along the eastern margin of the salt deposits where rock salt and gypsum have been removed by solution. These features are observed near spring areas in Woods County, Oklahoma, and in Cottle, Hall, and King Counties, Texas. The depressions coincide closely with the present eastern margin of the salt beds.

4. Southwest of Wichita, Kansas, in Sedgwick County, brine is present in strata of the Sumner Group that contain salt a short distance to the west. This brine is believed to originate from salt of the Wellington Formation.

5. Core samples taken near some of the springs show the presence of broken shale that contains salt casts. The slumped and broken nature of the shale can be attributed to the removal of salt that was, at one time, present in the shale as indicated by the salt casts.

6. The occurrence of salt casts and cubic voids in surface rock exposures and the presence of salt in the same strata at greater depths are evidence that salt was present but has been removed by solution.

7. Water samples collected from five springs and analyzed for tritium (T or H_3) content by the Geological Survey, Ground and Quality of Water Branches, indicated that the spring waters were mostly meteoric in origin and younger than 20 years.

Thus, it can be assumed that most underground water has its source in nearby areas--considering the low permeabilities of the confining rocks and the time that would be required for water to migrate great distances through such rock. An idealized sketch of the apparent movement of ground waters and its action on salt-bearing formations is shown on Figure IV-5.

Description of Natural Salt Sources

Field investigations and monitoring stations data show that there are 15 primary natural salt sources with a total daily salt (NaCl) emission of approximately 13,000 tons per day. Ten of these sources are in the Red River basin and five in the Arkansas River basin. The roman numerals serve as identification and map reference numbers. General location of these sources is shown on Figure IV-6.

Great Salt Plains of the Salt Fork of Arkansas River - Area I

The Great Salt Plains are in the valley of the Salt Fork of Arkansas River about 6 miles east of Cherokee, Oklahoma. It is located in Alfalfa County at about river mile 108 of the Salt Fork of Arkansas River (Figure IV-7).

Description of Area

This relatively flat and depression-like alluvial plain covers about 45 square miles, 30 square miles of which are noticeably salt encrusted during dry periods. Salt springs and seeps are not observable, but the fine sand and silt are saturated with salt water to within inches of the surface. The basin-like feature of the plain may have formed from the collapse of the Hennessey--a result, in part, of salt removal by underground water and erosion by surface streams. Stratigraphically, the salt strata are in the lower part of the "upper salt zone." In other nearby areas, the same strata contain salt that is being dissolved slowly by ground water.

Brine Emission

Ground water in the surficial deposits above the salt plain percolates down to the relatively shallow depth of the salt zone and becomes salt laden. The saline ground water then flows downslope into the alluvium of the plain and through the alluvium into the Salt Plains Reservoir. During dry periods, some of the water in the alluvium rises to the surface, evaporates, and deposits salt to form the encrusted surface of the plain. During periods of rainfall and surface runoff, the salt on the plain is dissolved and carried into the reservoir.

The area of emission of saline ground water is considered to be the salt encrusted plain plus the reservoir area which together cover approximately 45 square miles. Both the amount of brine emission and its concentration vary greatly. Only limited data, consisting of water samples in the lake and a few shallow ground water samples taken on the salt plain, are available on subsurface flow characteristics.

The lake water shows occasional stratification as the heavier mineral-laden water tends to sink to the bottom. The observed ranges in chloride ion concentrations vary from 300 to 13,000 milligrams per liter (mg/l) for surface water. Analyses of the water of the area are given on Table IV-6.

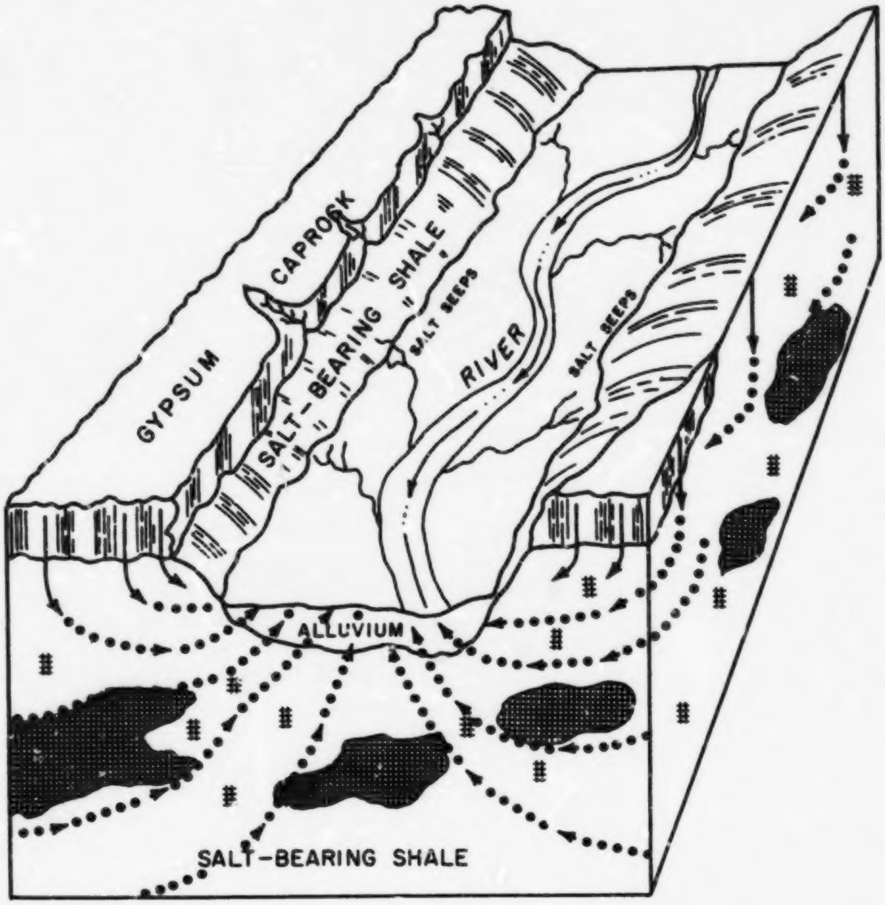
Salt Load

Salt loads entering Salt Fork of the Arkansas River from the Great Salt Plains are shown by the records for Station 235, immediately downstream from the dam of the Great Salt Plains Reservoir. They indicate that an influx of 270 cubic feet per second (cfs) results in a load increase of 1,400 tons per day of chloride and 50 tons per day sulfate.

Salt Fork of the Arkansas River Downstream from Area I

Below the Great Salt Plains Reservoir, the Salt Fork flows about 103 miles to its confluence with the Arkansas River. Records of salt loads at Station 236 near Tonkawa, Oklahoma, show a gain in chloride content of about 250 tons per day along this reach of stream. However, salt springs and seeps are not in evidence, and small amounts of oilfield brine pollution detected in the area near Tonkawa are believed to be insignificant.

The river throughout this reach traverses Quaternary dune sand and alluvium. Beneath the alluvium are found Permian rocks of the El Reno Group and Sumner Group. Brine emission in this area is believed to enter the Salt Fork and its tributary streams directly from saline ground water flows in the underlying alluvium and rock formations.


GYPSUM
CAPROCK
SALT-BEARING SHALE
SALT SEEPS
RIVER
SALT SEEPS
ALLUVIUM
SALT-BEARING SHALE

LEGEND:

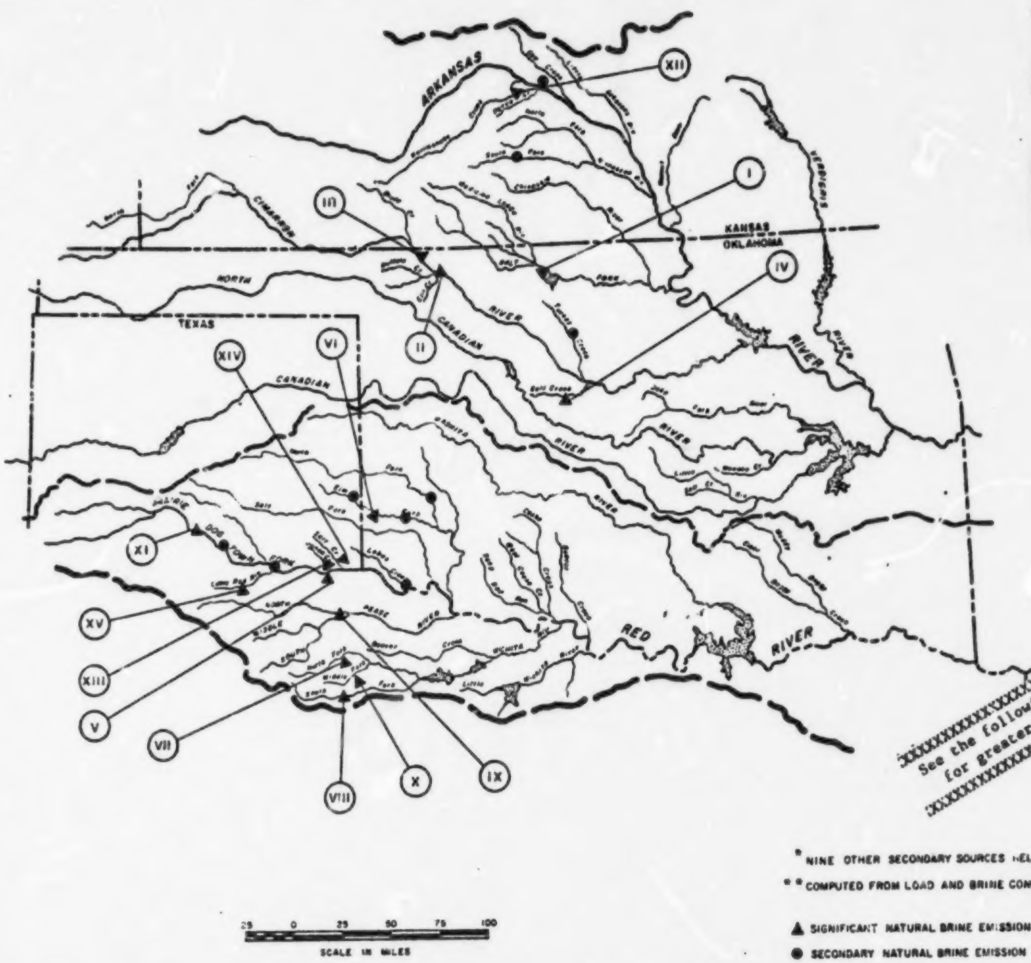
- ▨ BEDDED SALT
- ♯ ♯ ♯ DISSEMINATED SALT
- ——→ FRESH GROUND WATER
- ••••••••→ SALTY GROUND WATER

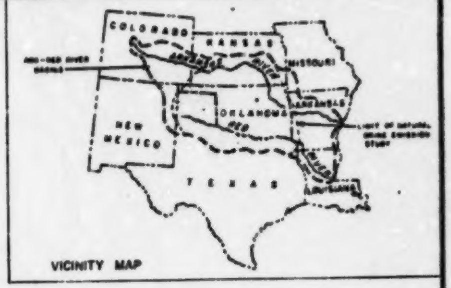
ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

IDEALIZED SKETCH OF GROUND WATER MOVEMENT AND ACTION ON SALT-BEARING FORMATIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-5


N
ARKANSAS
CIMARRON
NORTH
CANADIAN
RIVER
KANSAS
OKLAHOMA
TEXAS
RED
RIVER
VERDIGRIS
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV
XV
25 0 25 50 75 100
SCALE IN MILES


COLORADO
KANSAS
MISSOURI
ARKANSAS
OKLAHOMA
NEW MEXICO
TEXAS
LOUISIANA
ARK-RED RIVER BASINS
LIMIT OF NATURAL BRINE EMISSION STUDY

VICINITY MAP

SIGNIFICANT *NATURAL BRINE EMISSION AREAS

AREA NO	LOAD - TONS/DAY, AVERAGE As Chloride	 As Salt (NaCl)	ESTIMATED CONCENTRATED BRINE FLOW ** (CFS)
	Load computed from 1961-62 Water Years Study		
I	1400	2310	5
II	2950	4867	10
III	600	990	2
IV	220	360	1
V	375	620	8
VI	250	410	1
VII	200	330	2
VIII	200	330	2
IX	350	580	2
X	50	80	1
XI	175	290	2
XII	200	330	2
XIII	450	740	4
XIV	150	250	2
XV	150	250	1

XXXXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXXXX

* NINE OTHER SECONDARY SOURCES RELEASE ABOUT 1,050 TONS CHLORIDE/DAY.

** COMPUTED FROM LOAD AND BRINE CONCENTRATION.

▲ SIGNIFICANT NATURAL BRINE EMISSION AREA

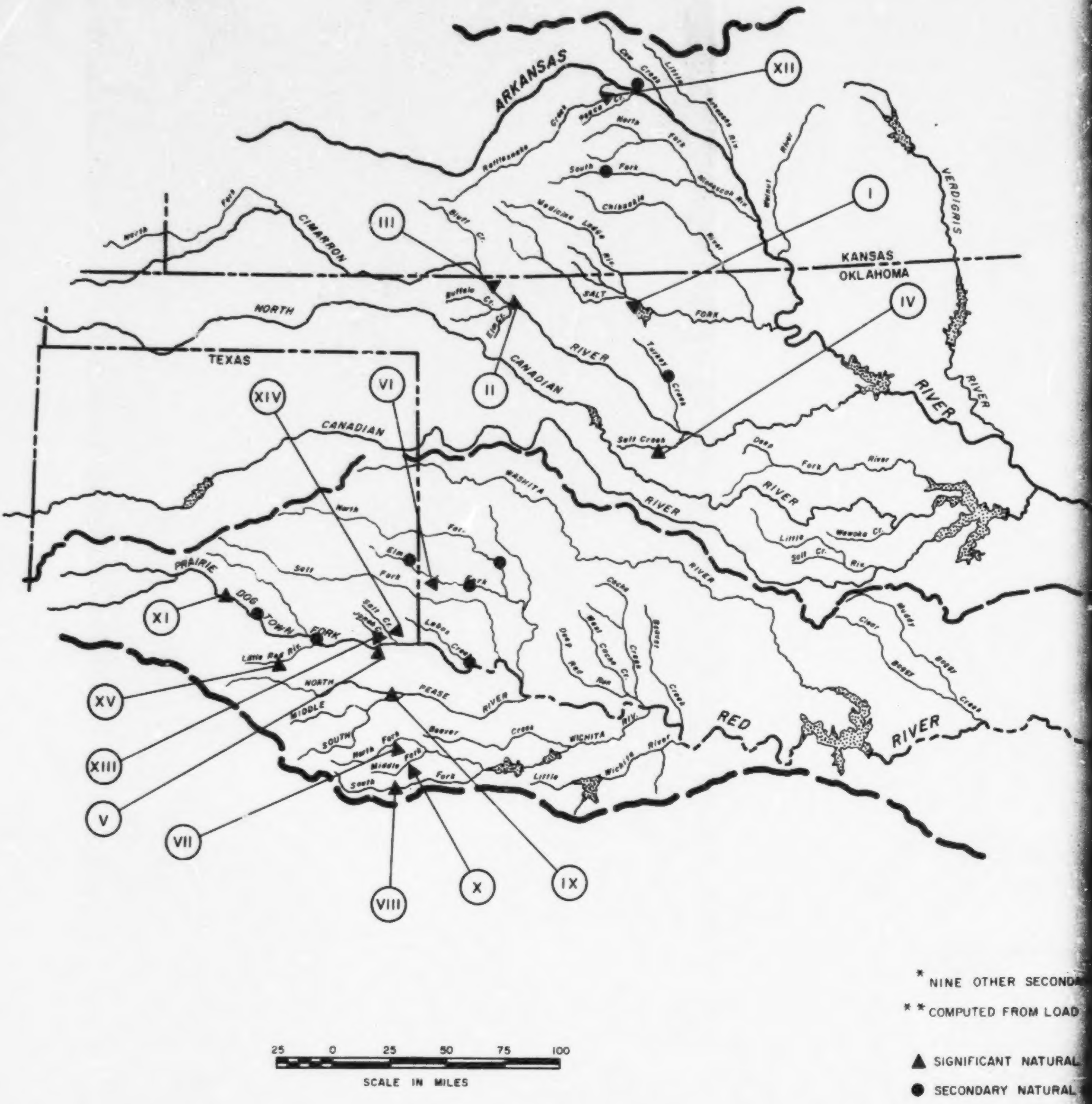
● SECONDARY NATURAL BRINE EMISSION AREA.

ARKANSAS—RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

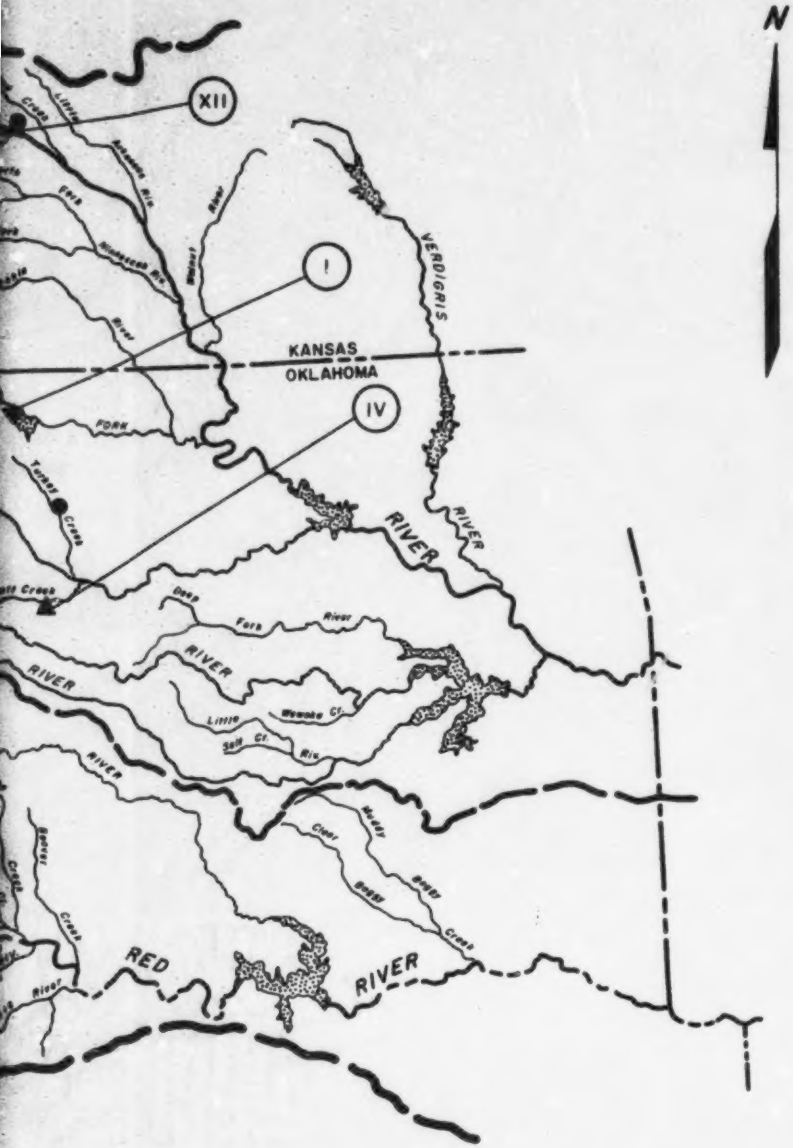
LOCATION OF NATURAL
BRINE EMISSIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-6


ARKANSAS
CIMARRON
North Fork
KANSAS
OKLAHOMA
TEXAS
NORTH CANADIAN RIVER
CANADIAN
VERDIGRIS RIVER
RIVER
WASHITA RIVER
Deep Fork River
RIVER
Little Rattlesnake Creek
Cow Creek
Little Arkansas Riv.
Rattlesnake Creek
Peace Cr.
North Fork
South Fork
Ninnescah Riv.
Walnut River
Medicine Lodge Riv.
Chikaskia River
Bluff Cr.
Buffalo Cr.
Elm Cr.
SALT FORK
Turkey Creek
Salt Creek
Little Salt Cr. Riv.
Wewoka Cr.
North Fork
Elm Fork
Salt Fork
PRAIRIE DOG TOWN FORK
Salt Cr.
Jonah Cr.
Lebos Creek
Little Red Riv.
NORTH PEASE RIVER
MIDDLE
SOUTH
North Fork
Middle Fork
South Fork
Beaver Creek
WICHITA RIV.
Little Wichita River
Cache Creek
West Cache Cr.
Deep Red Run
Beaver Creek
RED RIVER
Clear Boggy Creek
Muddy Boggy Creek
I
II
III
IV
V
VI
VII
VIII
IX
X
XI
XII
XIII
XIV
XV
* NINE OTHER SECOND
* * COMPUTED FROM LOAD
▲ SIGNIFICANT NATURAL
● SECONDARY NATURAL
25 0 25 50 75 100
SCALE IN MILES

A


N
XII
I
IV
KANSAS
OKLAHOMA
VERDIGRIS
RIVER
RIVER
Little
Arkansas Riv
Ninnescah Riv
Walnut
Fork
River
Turkey Creek
Salt Creek
Deep Fork River
RIVER
RIVER
Little
Wewoka Cr.
Salt Cr.
Riv
RIVER
Clear
Muddy
Boggy
Creek
Beaver
Creek
RED
RIVER
River

COLORADO
KANSAS
ARK-RED RIVER BASINS
ARKANSAS
RIVER
NEW MEXICO
OKLAHOMA
RED
TEXAS

VICINITY MAP

SIGNIFICANT *NATURAL BRINE EMISSION

AREA NO.	LOAD-TONS/DAY, AVERAGE As Chloride	 As Salt (NaCl)	ES CONC BRI
	Load computed from 1961-62 Water Years Study		
I	1400	2310	
II	2950	4960	
III	600	990	
IV	220	360	
V	375	620	
VI	250	410	
VII	200	330	
VIII	200	330	
IX	350	580	
X	50	80	
XI	175	290	
XII	200	330	
XIII	450	740	
XIV	150	250	
XV	150	250	

* NINE OTHER SECONDARY SOURCES RELEASE ABOUT 1,060 TONS CHLORIDE/DAY.

** COMPUTED FROM LOAD AND BRINE CONCENTRATION.

▲ SIGNIFICANT NATURAL BRINE EMISSION AREA.

● SECONDARY NATURAL BRINE EMISSION AREA.

ARKANSAS-RED
WATER QUALITY CONSE

LOCATION OF
BRINE EMI

U.S. DEPARTMENT OF HEALT
PUBLIC HEALT
REGION VII

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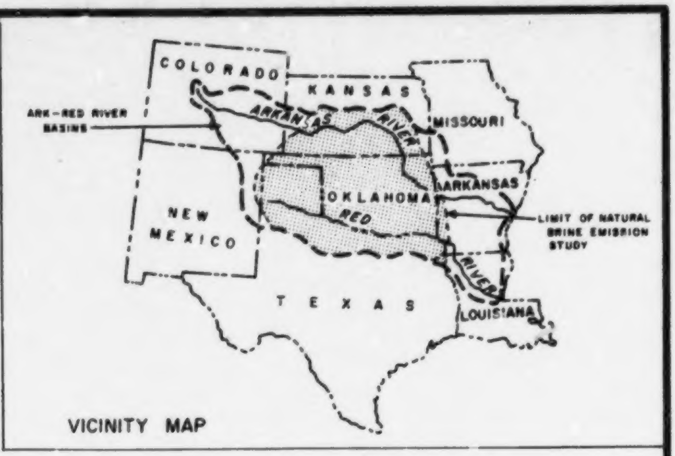

COLORADO
KANSAS
MISSOURI
ARK-RED RIVER BASINS
ARKANSAS RIVER
OKLAHOMA
ARKANSAS
NEW MEXICO
RED RIVER
LIMIT OF NATURAL BRINE EMISSION STUDY
TEXAS
LOUISIANA

VICINITY MAP

SIGNIFICANT *NATURAL BRINE EMISSION AREAS

AREA NO.	LOAD-TONS/DAY, AVERAGE As Chloride	 As Salt (NaCl)	ESTIMATED CONCENTRATED BRINE FLOW ** (CFS)
	Load computed from 1961-62 Water Years Study		
I	1400	2310	5
II	2950	4960	10
III	600	990	2
IV	220	360	1
V	375	620	5
VI	250	410	1
VII	200	330	2
VIII	200	330	2
IX	350	580	2
X	50	80	1
XI	175	290	2
XII	200	330	2
XIII	450	740	4
XIV	150	250	2
XV	150	250	1

SECONDARY SOURCES RELEASE ABOUT 1,060 TONS CHLORIDE/DAY.

OM LOAD AND BRINE CONCENTRATION.

NATURAL BRINE EMISSION AREA

NATURAL BRINE EMISSION AREA.

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

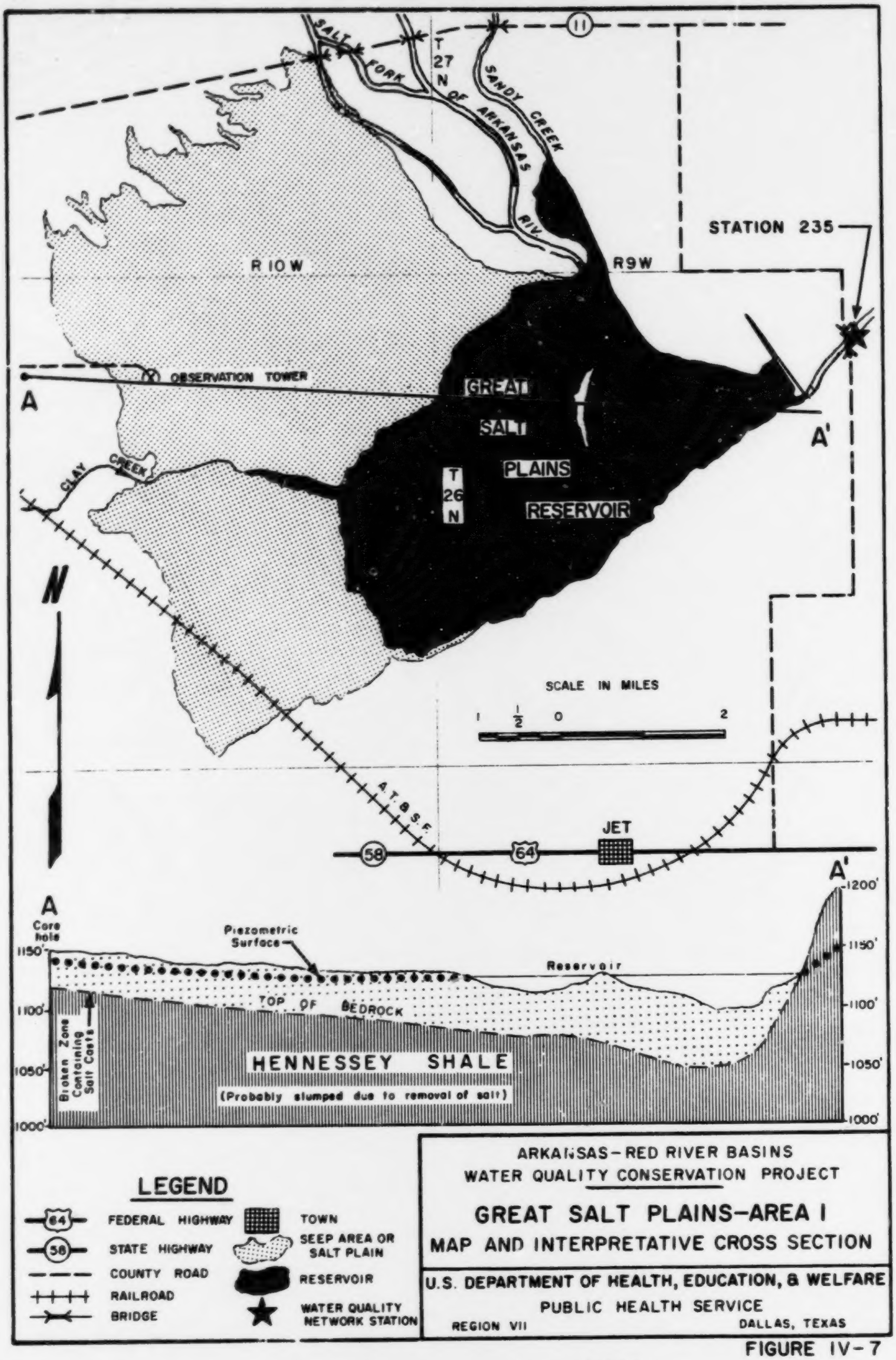
LOCATION OF NATURAL
BRINE EMISSIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

B

FIGURE IV-6

e


SALT FORK OF ARKANSAS RIV.
SANDY CREEK
T 27 N
11
STATION 235
R 10 W
R9W
OBSERVATION TOWER
A
A'
GREAT SALT PLAINS RESERVOIR
T 26 N
CLAY CREEK
N
SCALE IN MILES
1 1/2 0 2
A.T.&S.F.
58
64
JET
A
Core hole
A'
Piezometric Surface
Reservoir
TOP OF BEDROCK
HENNESSEY SHALE
(Probably slumped due to removal of salt)
Broken Zone Containing Salt Casts
1150'
1100'
1050'
1000'
1200'
1150'
1100'
1050'
1000'
LEGEND
64 FEDERAL HIGHWAY
58 STATE HIGHWAY
COUNTY ROAD
RAILROAD
BRIDGE
TOWN
SEEP AREA OR SALT PLAIN
RESERVOIR
WATER QUALITY NETWORK STATION

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

GREAT SALT PLAINS-AREA I
MAP AND INTERPRETATIVE CROSS SECTION

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-7

Table IV-6

Chemical Analyses of Natural Brines, Great Salt Plains - Area I

	Collection Point*				
	At Tower 1' Deep	3 Miles S. of Tower 1½' Deep	150' NE of Tower 1' Deep	75' SW of Tower 2' Deep	150' NW of Tower 2½' Deep
Date Collected	1-5-60	5-19-60	5-19-60	5-19-60	9-13-60
pH	7.7	7.6	6.9	7.0	7.4
Specific Gravity, 20°C	1.1338	1.0655	1.1621	1.1218	1.1721
Spec. cond. 25°C, micromhos/cm	190,000	27,000	210,000	160,000	170,000
Total alkalinity ($CaCO_3$)	92	340	130	90	92
Total hardness ($CaCO_3$)	6,250	1,100	8,800	5,600	8,800
Dissolved solids	221,600	16,400	265,600	194,600	273,800
Calcium (Ca)	1,140	240	1,520	1,200	1,120
Magnesium (Mg)	835	120	1,215	630	1,460
Sodium (Na)	87,500	6,800	102,000	73,500	102,500
Potassium (K)	140	50	220	150	140
Sulfate (SO_4)	5,250	900	7,350	5,350	6,600
Chloride (Cl)	129,500	9,500	153,500	113,000	161,000
Iron (Fe)	0.32	0	0	0	0
Silica (SiO_2)	3.8	16.4	7.6	6.8	
Boron (B)	2.0	0.2	1.0	1.5	1.1
Fluoride (F)	0.8	4.0	4.0	4.0	3.3
Iodine (I)	0.2				
Bromine (Br)	20	20	20	20	60
Manganese (Mn)		0	0	0	0

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

*Relative to Tower at west side of plain.

Big Salt Plains of the Cimarron River - Area II

This salt plain includes about 8 square miles of the flood plain of the Cimarron River in parts of Woods, Woodward, and Harper Counties, Oklahoma (Figure IV-8).

Description of the Area

The Big Salt Plains are a broad, flat, alluvial surface that occupies the flood plain of the Cimarron River. The floor of the plain is encrusted with crystallized salt of varying thickness.

Brine Emission

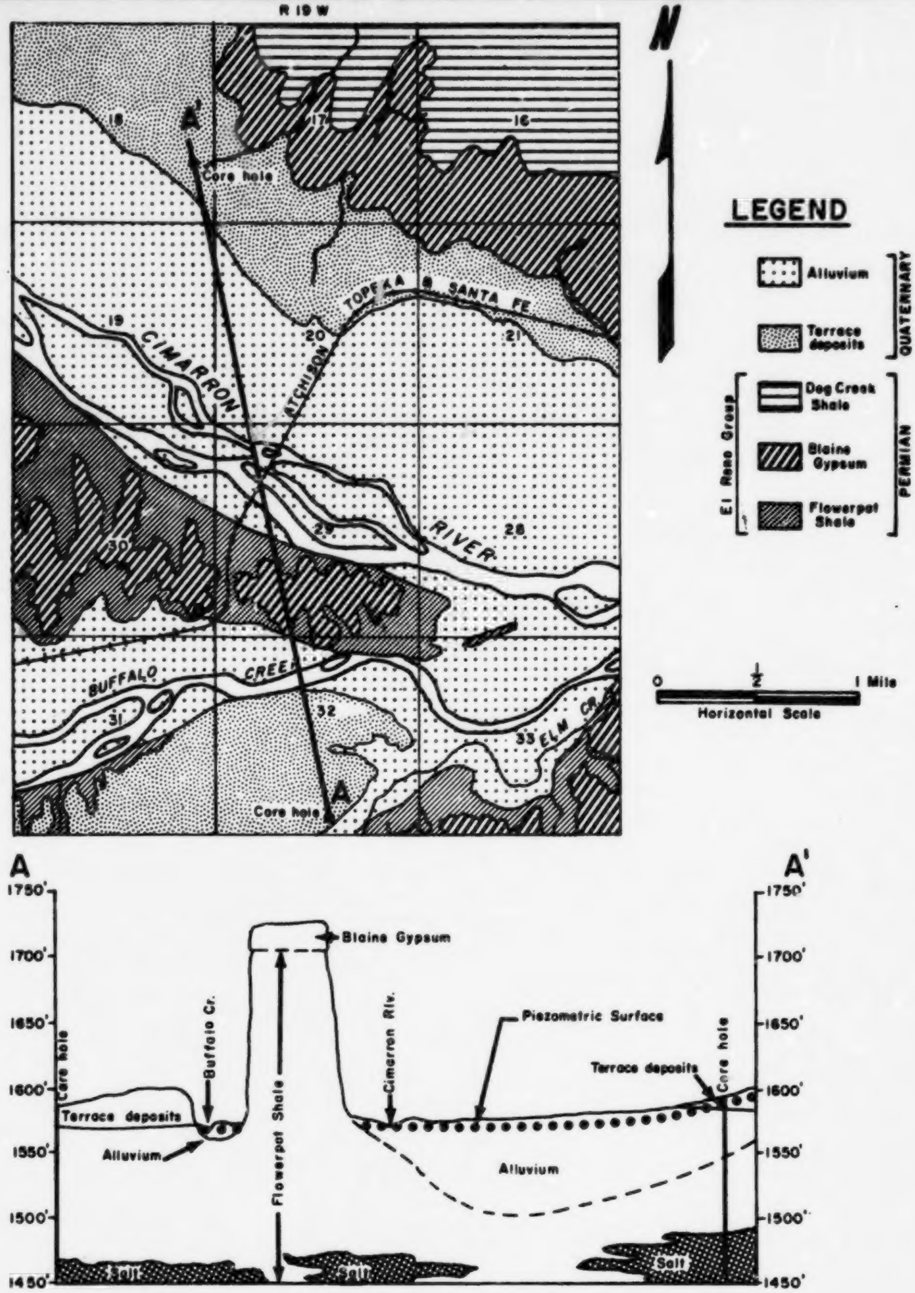
Small springs and seeps of saturated brine (containing about 26 percent NaCl) occur along the northern and southern margins of the plains and along the banks of Buffalo and Elm Creek canyons. Evaporation of these brines during periods of dry weather causes salt to accumulate on the surface of the plain. Deposits of salt up to 3 and 4 inches in thickness have been observed at the confluence of Buffalo and Elm Creeks. Accumulation of solid salt on the flood plain can amount to 125,000 tons during periods of dry weather. In addition to the salt crust, the alluvium is saturated with brine waters of varying salt concentration. Samples of brines, taken in the alluvium at the lower end of the Big Salt Plains, between Sand and Moccasin Creeks, show a marked increase in concentrations with depth.

The chloride contribution from springs in the area is estimated at 1,600 tons per day. The visible salt springs do not account for the total salt load contributed to the river in the salt plain area. The additional load is added by salt water seeping from the bedrock directly into the overlying alluvial sand.

Analyses of the area water are given on Table IV-7.

Salt Load

The chloride and sulfate contamination of the Cimarron River from this area has been interpolated from the results obtained for Station 248 which is a short distance below the plain. This shows an influx of about 110 cubic feet per second and results in a load increase to the river of 2,950 tons per day of chloride and 75 tons per day of sulfate.


R 19 W
N
A'
A
Core hole
16
17
18
19
20
21
28
29
30
31
32
33
CIMARRON
RIVER
ATCHISON
TOPEKA & SANTA FE
BUFFALO
CREEK
ELM CR.
LEGEND
Alluvium
Terrace deposits
QUATERNARY
Dog Creek Shale
Blaine Gypsum
Flowerpot Shale
El Reno Group
PERMIAN
0
½
1 Mile
Horizontal Scale
1750'
1700'
1650'
1600'
1550'
1500'
1450'
Blaine Gypsum
Piezometric Surface
Buffalo Cr.
Cimarron Riv.
Core hole
Terrace deposits
Alluvium
Flowerpot Shale
Salt

ARKANSAS—RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

BIG SALT PLAINS—AREA II

MAP AND INTERPRETATIVE CROSS SECTION

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-8

Table IV-7

Chemical Analyses of Natural Brines, Big Salt Plains of the Cimarron River - Area II

	Collection Point				
	Ground Water Sample 2.5' Deep Near Blackmon's Ranch	Brine Spring South Bank of Buffalo Creek	Blackmon's Brine Well 500' SW of House	Blackmon's Brine Well 1,000' WSW of House	Blackmon's Brine Well ½ Mile SE of House
Date Collected	9-13-60	5-19-60	5-26-60	5-26-60	5-26-60
pH	7.3	6.9	5.6	4.1	4.1
Specific Gravity, 20°C	1.2132	1.1953	1.1930	1.1685	1.1944
Spec. cond. 25°C, micromhos/cm		210,000	210,000	220,000	220,000
Total alkalinity ($CaCO_3$)	28	30	20	20	20
Total hardness ($CaCO_3$)	7,200	8,000	6,400	7,200	6,800
Dissolved Solids	313,500	317,800	318,400	276,700	320,300
Calcium (Ca)	1,520	1,440	1,440	1,840	1,200
Magnesium (Mg)	825	1,070	680	630	925
Sodium (Na)	118,800	110,000	108,000	103,000	110,000
Potassium (K)	140	2230	200	170	230
Sulfate (SO_4)	3,500	4,950	4,500	3,800	4,500
Chloride (Cl)	189,000	189,500	189,000	159,000	189,000
Iron (Fe)	0.10	0	Trace	62.5	3.2
Silica (SiO_2)		3.4	1.8	1.8	0.08
Boron (B)	2.0	1.7	1.6	4.7	
Fluoride (F)	2.8	3.2	2.0	0.5	2.0
Iodine (I)					
Bromine (Br)	20	20	20	20	20
Manganese (Mn)		0	Trace	1.8	0.1

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

Little Salt Plains of the Cimarron River - Area III

This salt plain is approximately 2 square miles in area and includes parts of Harper and Woods Counties in Oklahoma about 2 miles south of the Kansas border. The plain is located near river mile 298 of the Cimarron River upstream from Big Salt Plains (Area II) as shown on Figure IV-9.

Description of the Area

The Little Salt Plains are on the Quaternary alluvium of the river bed and have as their bedrock the Flowerpot Shale. This formation also is exposed on the cliffs which border the river. The upper part of these cliffs and caprock is composed of the Blaine Formation. Farther away from the river, the Dog Creek Shale and Whitehorse Group cap the higher ridges. Salt encrustations are visible in the outcropping shale several feet below the base of the overlying Blaine gypsum. The rock sequences and their lithologic character are essentially the same as in the Big Salt Plains (Area II) but only the upper 20 to 30 feet of the Flowerpot Shale is exposed in this area.

Brine Emission

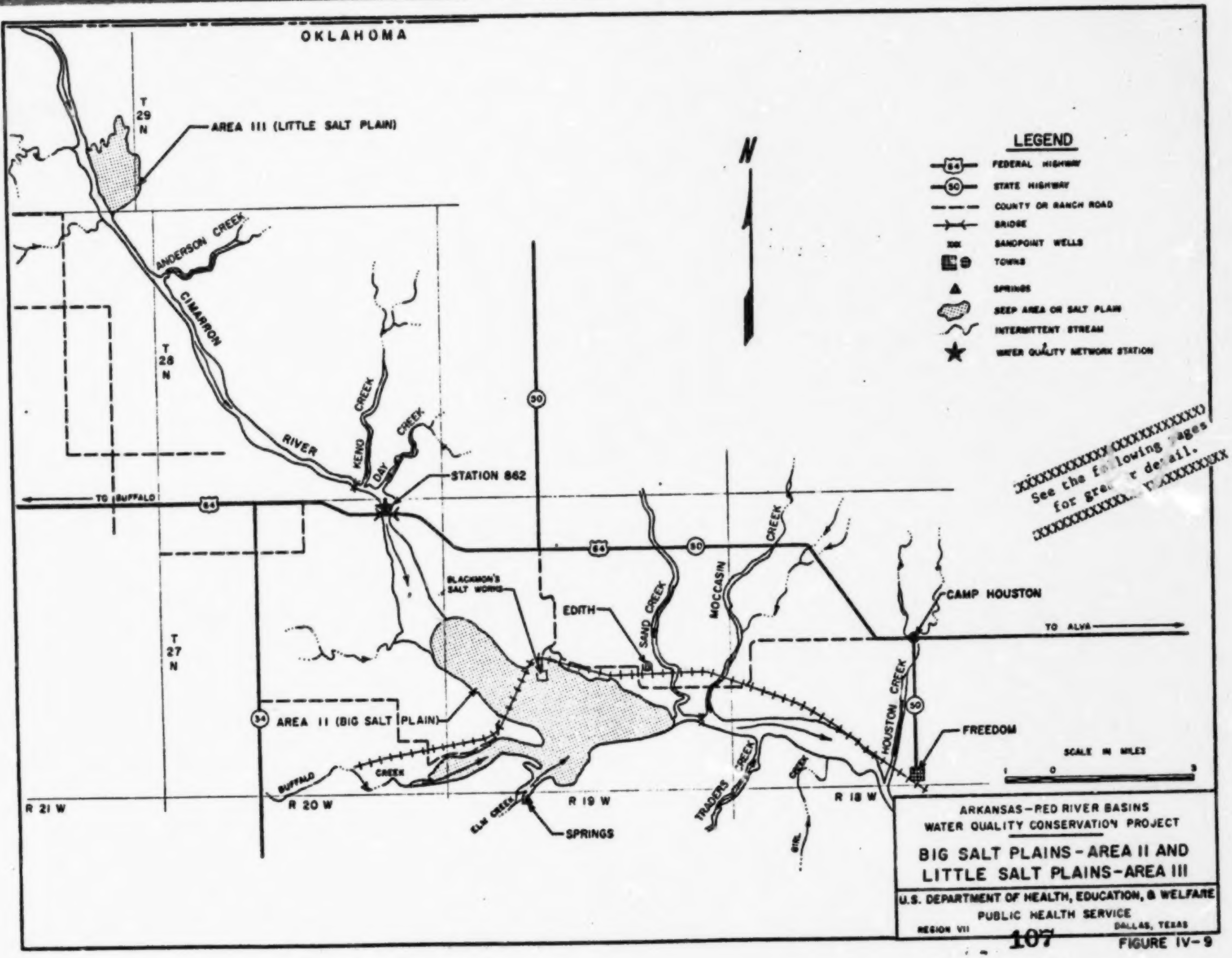
The alluvial fill in the Cimarron River valley ranges up to 80 feet in thickness in this area and is saturated with brine waters of varying chloride concentration. Salt springs have not been observed at Little Salt Plains, but small seeps were observed. Salt water moves toward the river from both sides. The dune sand and terrace deposits on the north side and the fractured shale and gypsum on the south side facilitate the downward flow of ground water to the salt-bearing strata and then into the alluvium.

Both chloride and sulfate concentrations increase with depth in the alluvium. In addition to storage of brine in the alluvium, salt accumulates in a crust-like layer on the surface of the plain.

Analyses of the area water are given on Table IV-8.

Salt Loads

The Cimarron River contamination load from this area, as recorded by Station 862, is about 600 tons per day chloride and 20 tons per day sulfate.


OKLAHOMA
T 29 N
AREA III (LITTLE SALT PLAIN)
ANDERSON CREEK
CIMARRON
RIVER
T 28 N
KENO CREEK
DAY CREEK
STATION 862
TO BUFFALO
64
50
BLACKMON'S SALT WORKS
EDITH
SAND CREEK
MOCCASIN CREEK
CAMP HOUSTON
TO ALVA
HOUSTON CREEK
FREEDOM
T 27 N
34
AREA II (BIG SALT PLAIN)
BUFFALO CREEK
ELM CREEK
SPRINGS
TRADERS CREEK
GIRL CREEK
R 21 W
R 20 W
R 19 W
R 18 W
N
LEGEND
FEDERAL HIGHWAY
STATE HIGHWAY
COUNTY OR RANCH ROAD
BRIDGE
SANDPOINT WELLS
TOWNS
SPRINGS
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
WATER QUALITY NETWORK STATION
SCALE IN MILES
1 0 3

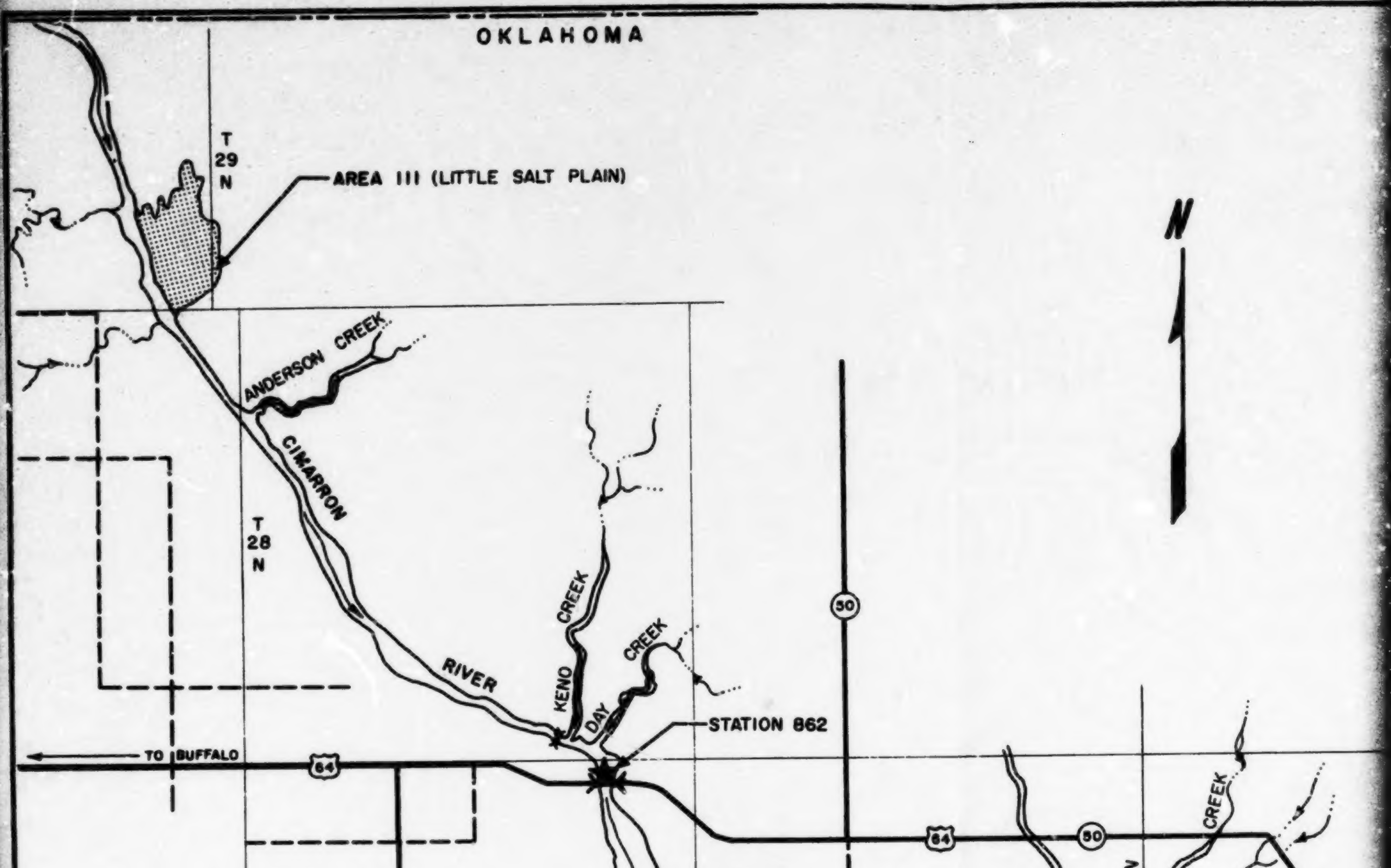
See the following pages
for greater detail.

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

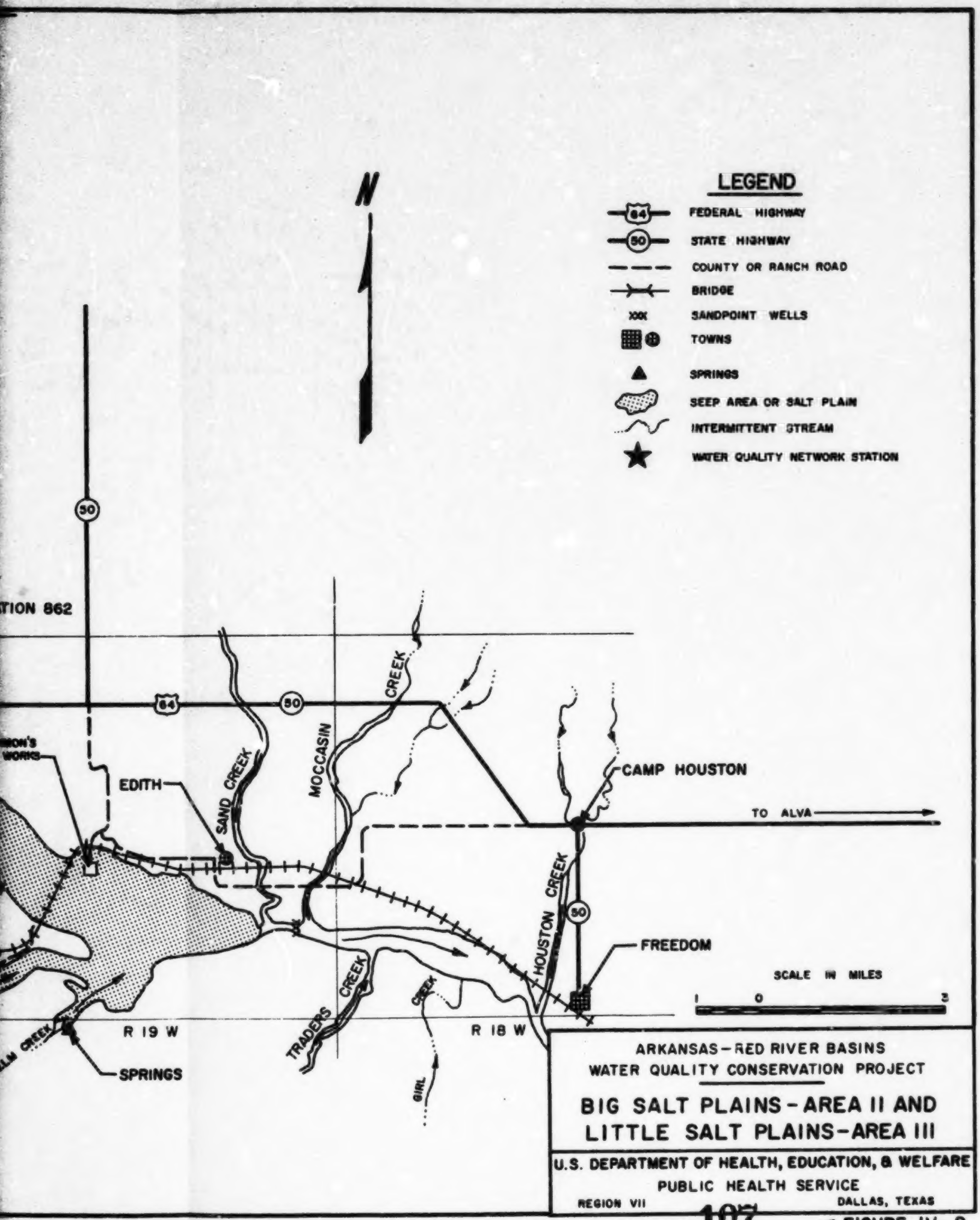
BIG SALT PLAINS - AREA II AND
LITTLE SALT PLAINS - AREA III

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-9


OKLAHOMA
T 29 N
AREA III (LITTLE SALT PLAIN)
N
ANDERSON CREEK
CIMARRON
T 28 N
RIVER
KENO CREEK
DAY CREEK
STATION 862
TO BUFFALO
64
50
64
50
BLACKMON'S SALT WORKS
EDITH
SAND CREEK
MOCCASIN CREEK
T 27 N
34
AREA II (BIG SALT PLAIN)
BUFFALO
CREEK
ELM CREEK
SPRINGS
TRADERS CREEK
CREEK
GIRL
R 21 W
R 20 W
R 19 W
R 18 W

A


N
LEGEND
64 FEDERAL HIGHWAY
50 STATE HIGHWAY
COUNTY OR RANCH ROAD
BRIDGE
xxx SANDPOINT WELLS
TOWNS
SPRINGS
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
WATER QUALITY NETWORK STATION
50
ATION 862
64
50
WORKS
EDITH
SAND CREEK
MOCCASIN
CREEK
CAMP HOUSTON
TO ALVA
HOUSTON CREEK
50
FREEDOM
SCALE IN MILES
1 0 3
TRADERS CREEK
CREEK
GIRL
ELM CREEK
R 19 W
R 18 W
SPRINGS

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

BIG SALT PLAINS-AREA II AND
LITTLE SALT PLAINS-AREA III

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

B FIGURE IV-9

Table IV-8

Chemical Analyses of Natural Brines, Little Salt Plains of the Cimarron River - Area III

	Collection Point	
	Brine Seep on East Side of Salt Plain Sec. 25 T29N, R21W, Woods Co.	Shallow Ground Water - Less than 3' in Depth
Date Collected	11-17-59	1-6-60
pH	6.7	7.2
Specific Gravity, 20°C	1.204	1.0636
Spec. cond. 25°C, micromhos/cm	215,000	125,000
Total alkalinity ($CaCO_3$)		284
Total hardness($CaCO_3$)	7,570	4,000
Dissolved Solids		107,500
Calcium (Ca)	1,540	1,040
Magnesium (Mg)	910	340
Sodium (Na)	125,000	42,500
Potassium (K)		95
Sulfate (SO_4)	4,560	1,440
Chloride (Cl)	194,000	61,000
Iron (Fe)		0.12
Silica (SiO_2)	2.5	14.6
Boron (B)	2.0	1.0
Fluoride (F)		0.9
Iodine (I)		0.2
Bromine (Br)		10
Manganese (Mn)		

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

Salt Creek of the Cimarron River - Area IV

Salt Creek enters the Cimarron River about 9 miles east of Okeene, Oklahoma, at about river mile 179. From this point in Kingfisher County, the creek extends in a southwesterly direction approximately 20 miles to its source in Blaine County (Figure IV-10).

Description of the Area

Salt Creek has its source along the base of a steep, eastward-facing escarpment that is capped by Dog Creek Shale and the Blaine Formation, and is underlain by the Flowerpot Shale (Figure IV-11). All three of these major formations of the El Reno Group are suspected salt bearers. The Flowerpot has a thickness of up to 450 feet in this area; the Blaine, ranges from 75 to 100 feet in thickness; and the Dog Creek Shale is from 160 to 190 feet thick. The bedrock of Salt Creek is the Flowerpot Shale in the area of pollution and the Cedar Hill member of the Hennessey Shale in the lower part of the stream system. The United States Gypsum Company operates a plant at the head of Salt Creek Canyon, utilizing the Nescatunga and Shimer members of the Blaine Formation which are about 98 percent calcium sulfate.

Brine Emission

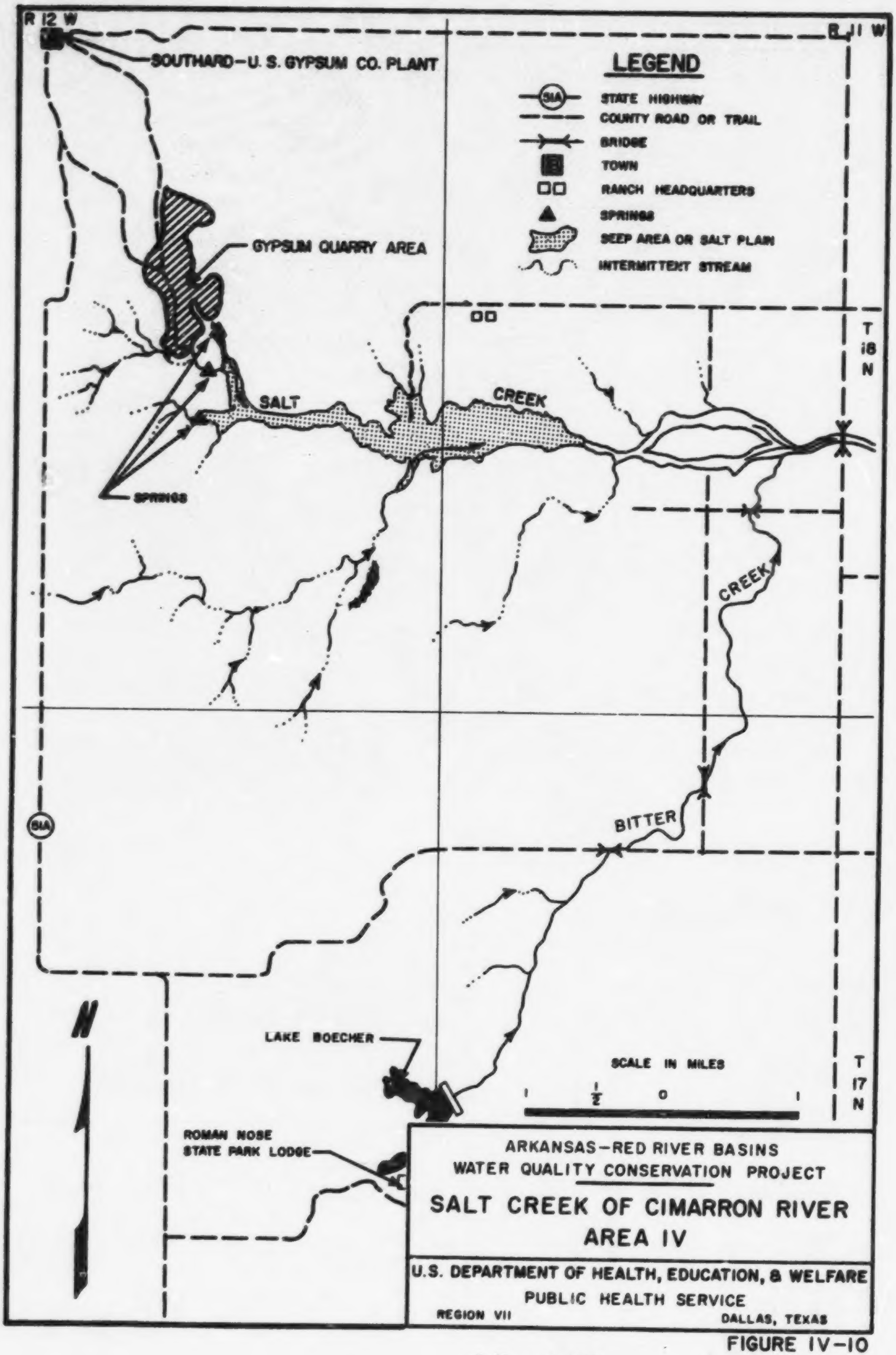
Ground water movement is up the regional dip, and toward the Salt Creek and Cimarron River valleys. One feature of the drainage between the North Canadian and Cimarron Rivers is the pattern produced by ephemeral and intermittent streams that do not reach the main rivers. Most of these streams are less than a mile long and end in a small sink or depression as an ephemeral lake. Sinkholes have developed in historic time in this region, probably due to solution of the underlying Blaine Formation.

Streamflow originates from fresh surface runoff and wet-weather springs, mainly in the overlying gravel and sand deposits that cover the uplands to the west. These deposits act as an aquifer, supplying water to the formations below, where the soluble salts of the Permian are taken into solution. Small salt water springs and seeps emerge from all levels of the escarpment in the canyons of the upper three miles of the system and then merge to form Salt Creek. The saline waters saturate the alluvium and, upon evaporation, form a large area of veneered crust of salt known locally as the Ferguson Salt Plain.

Analyses of waters from the area are given on Table IV-9.

Salt Load

Salt water seeping out of the escarpment raises the chloride ion content in the creek from a few to 10,000 mg/l or more, depending

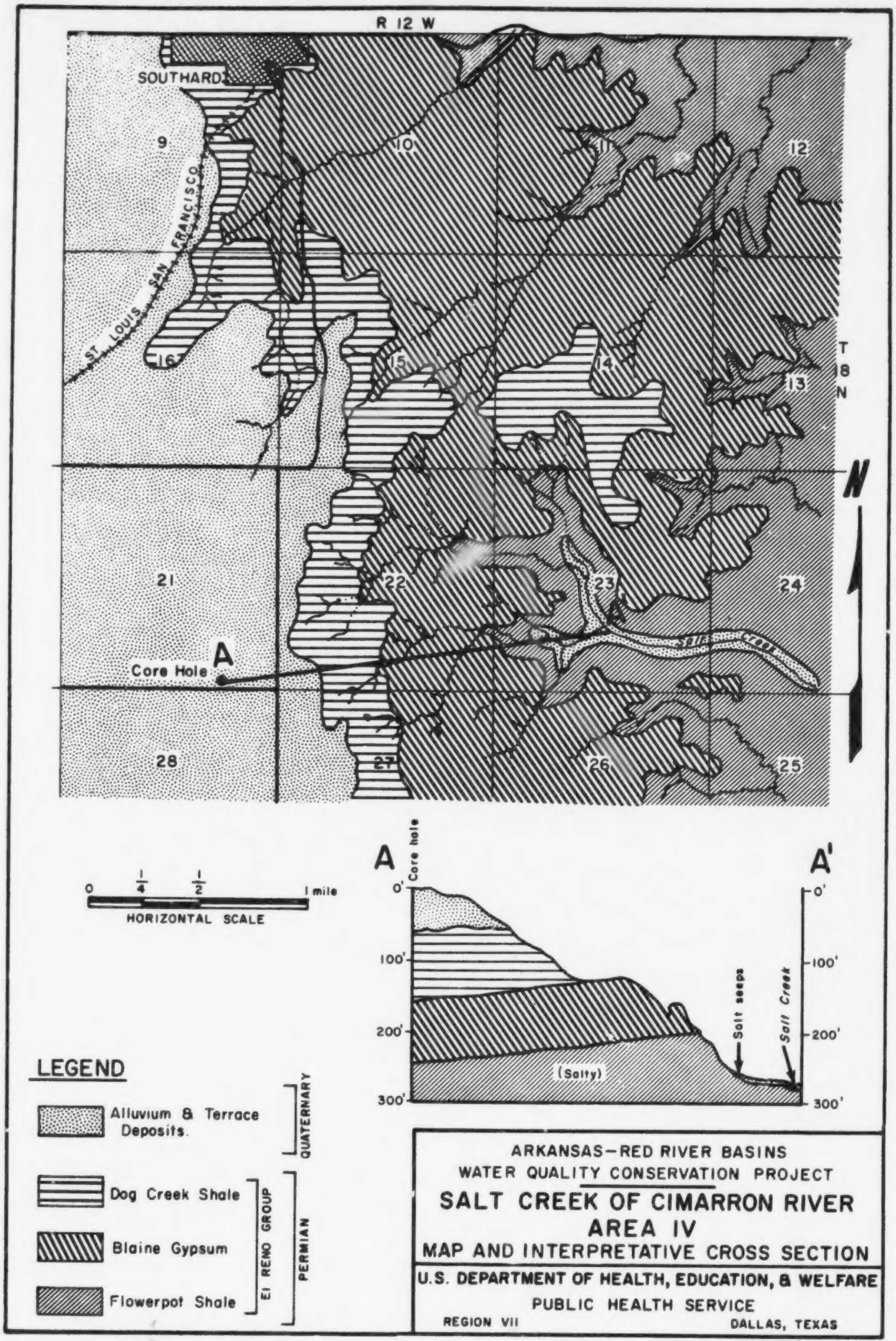

R 12 W
R 11 W
SOUTHARD–U. S. GYPSUM CO. PLANT
LEGEND
51A STATE HIGHWAY
COUNTY ROAD OR TRAIL
BRIDGE
TOWN
RANCH HEADQUARTERS
SPRINGS
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
GYPSUM QUARRY AREA
SALT
CREEK
SPRINGS
T 18 N
CREEK
BITTER
51A
LAKE BOECHER
ROMAN NOSE STATE PARK LODGE
SCALE IN MILES
1 ½ 0 1
T 17 N
N

ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

SALT CREEK OF CIMARRON RIVER
AREA IV

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV–10


R 12 W
SOUTHARD
ST. LOUIS SAN FRANCISCO
9
10
11
12
16
15
14
13
T 18 N
N
21
22
23
24
Salt Creek
A
Core Hole
28
27
26
25
0
$\frac{1}{4}$
$\frac{1}{2}$
1 mile
HORIZONTAL SCALE
A
A'
Core hole
0'
100'
200'
300'
Salt seeps
Salt Creek
(Salty)
LEGEND
Alluvium & Terrace Deposits.
QUATERNARY
Dog Creek Shale
Blaine Gypsum
Flowerpot Shale
El Reno Group
PERMIAN

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

SALT CREEK OF CIMARRON RIVER
AREA IV

MAP AND INTERPRETATIVE CROSS SECTION

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-11

Table IV-9

Chemical Analyses of Natural Brines
Salt Creek of the Cimarron River - Area IV

	Collection Point		
	Salt Creek North Canyon	Salt Creek Just Above Spring Creek	Salt Creek Spring at Head of North Canyon
Date Collected	11-16-59	11-16-59	8-15-60
pH	7.4	7.9	7.1
Specific Gravity, 20°C	1.102	1.009	1.0718
Spec. cond. 25°C, micromhos/cm	159,000	23,100	124,000
Total alkalinity ($CaCO_3$)			40
Total hardness ($CaCO_3$)	7,200	2,180	6,000
Dissolved Solids			107,000
Calcium (Ca)	1,870	666	1,760
Magnesium (Mg)	636	126	390
Sodium (Na)	57,300	4,650	37,000
Potassium (K)			100
Sulfate (SO_4)	3,520	1,770	5,600
Chloride (Cl)	90,800	7,280	63,500
Iron (Fe)			Trace
Silica (SiO_2)	4.0	6.5	7.2
Boron (B)	2.5	1.3	3.4
Fluoride (F)			3.4
Iodine (I)			
Bromine (Br)			34
Manganese (Mn)			0

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

upon the volume of fresh water flowing from higher elevations. An average of 220 tons per day of chloride and 10 tons per day of sulfate from this area has been measured by Station 769. Approximately 50 tons of chlorides originate in each of the north and south main canyons, and the remainder comes directly by subsurface flow into the streambed proper.

Turkey Creek of the Cimarron River

Turkey Creek enters the Cimarron River at river mile 162 near Dover in Kingfisher County, Oklahoma. Headwaters of the stream are near Helena in southern Alfalfa County. The area of salt pollution is an abandoned lakebed through which the stream flows. The ancient lakebed, known locally as Drummond Flat, is in western Garfield County.

Description of the Area

The abandoned lakebed has an area of about 12 square miles and is of probable Pleistocene age. The creek flows through Quaternary dune sand and lacustrine deposits which are underlain by the Cedar Hills Member of the Hennessey Shale. Turkey Creek meanders through this bottom land and provides the only means of drainage from the area. One tributary within the bottom land has intermittent flow and contains a light salt crust during dry weather. Salt water is reported at a depth of less than 5 feet beneath the central portion of the basin.

Water samples were collected about 4 miles below Drummond Flat by the Geological Survey at intervals from 1951 to 1959. The chloride content of the samples ranged from a few to 2,790 mg/l, and the chloride load averaged about 50 tons per day.

Rattlesnake Creek of the Arkansas River - Area XII

Rattlesnake Creek enters the Arkansas River about 3 miles southeast of Raymond, Kansas, at about river mile 841. From this point, the stream extends west about 7 miles to the area of salt pollution in the eastern part of Stafford County (Figure IV-12).

Description of the Area

Rattlesnake Creek is a meandering stream that has reached temporary base level. It is perennial from a few miles southwest of St. John during normal ground water conditions. The valley ranges in width from less than one-half to about 2 miles and is bordered by low bluffs of dune sand. Salty marshland occupies much of the valley near the eastern side of Stafford County. The largest salt marsh covers about 16 square miles and a smaller salt marsh about 2 square miles. The stream is diverted by manmade structures to flow through the Little Salt Marsh, but intermittent overflow from Big Salt Marsh enters the creek through a small tributary from the big marsh area.

The underlying rock in ascending order consists of Permian red beds, the Cheyenne Sandstone, and Kiowa Shale of early Cretaceous age, and the highly unconsolidated Meade Formation of Quaternary age. (Figure IV-13). The main salt bed of the area lies at a depth of 1,000 feet and has no relation to the surface pollution.

Brine Emission

The upper Permian and early Cretaceous beds which are known to contain waters of high salt content are found within 50 feet of the creek bed in the area of major pollution. Well samples taken from the Meade Formation show a high chloride content. It is believed that ground water flows over the Permian ridge which trends perpendicular to the direction of movement, and that this forces the mineralized waters through the overlying formations and into the creek bed. Evaporation of marsh waters tends to concentrate their salinity and leaves a residue of salt on the surface of the marsh.

Analyses of the area water are given on Table IV-10.

Salt Load

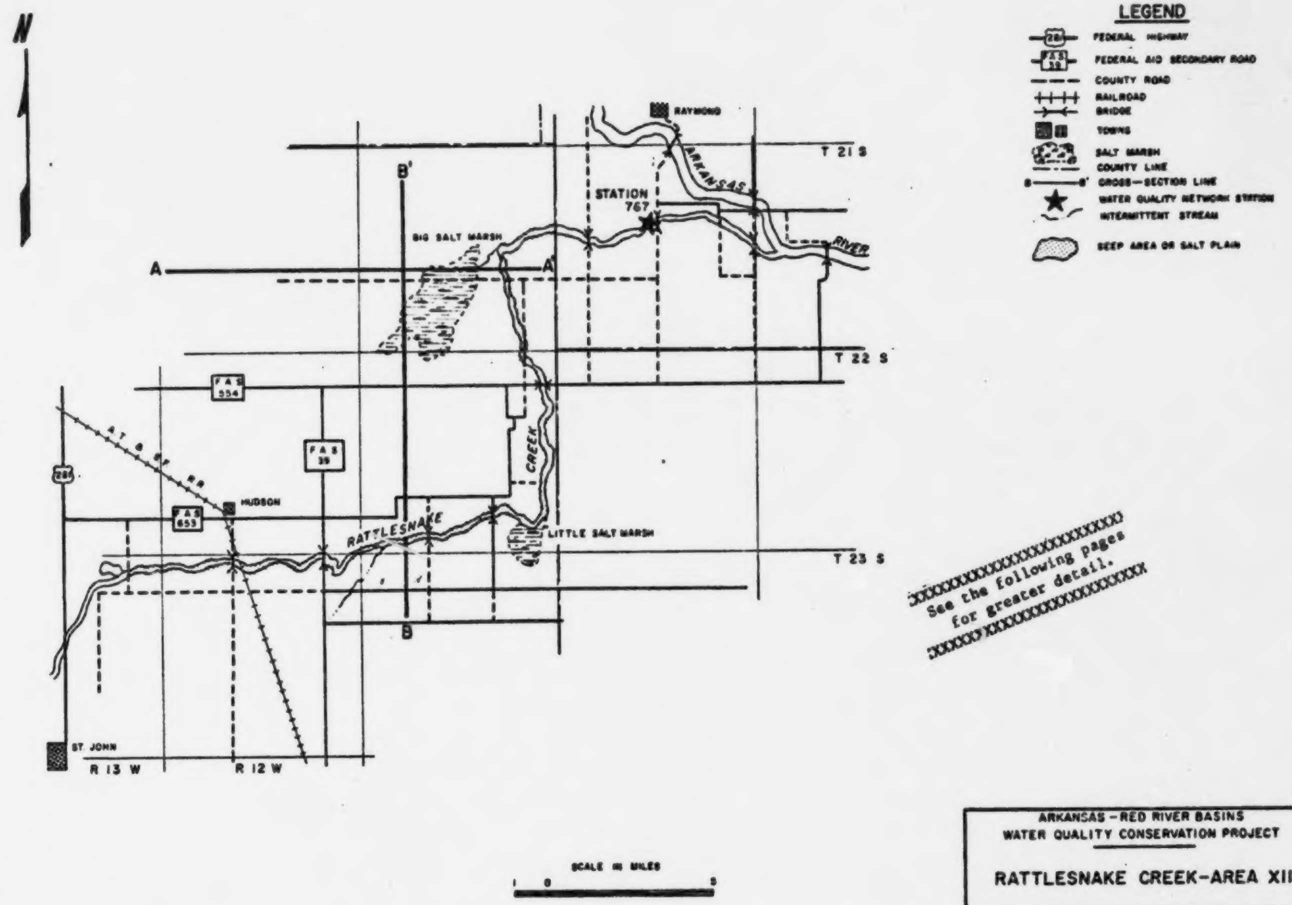
The chloride content of Rattlesnake Creek water, where it flows into the area of salt pollution, is generally less than 50 mg/1, but where the creek flows out of the county, the chloride content often exceeds 1,000 mg/1. An average chloride load of 200 tons per day and 10 tons per day of sulfate is transported from the area.

Table IV-10

Chemical Analyses of Natural Brines
Rattlesnake Creek - Area XII

	Collection Point	
	Seep at NW¼, SE¼, Sec. 2, T23S, R13W Stafford County, Kansas	Creek at SW¼ Sec. 1, T23S, R13W, Stafford County, Kansas
Date Collected	10-5-60	10-5-60
pH	8.2	8.1
Specific Gravity, 20°C	1.0085	0.9947
Spec. cond. 25°C, micromhos/cm	27,000	1,200
Total alkalinity ($CaCO_3$)	164	160
Total hardness ($CaCO_3$)	2,000	224
Dissolved solids	20,000	720
Calcium (Ca)	480	64
Magnesium (Mg)	194	16
Sodium (Na)	7,300	183
Potassium (K)	50	4
Sulfate (SO_4)	1,000	45
Chloride (Cl)	11,000	272
Iron (Fe)	0	0
Silica (SiO_2)		
Boron (B)	0.7	0.2
Fluoride (F)	1.8	0.7
Iodine (I)		
Bromine (Br)	20	20
Manganese (Mn)	0	0

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.


N
LEGEND
FEDERAL HIGHWAY
FEDERAL AID SECONDARY ROAD
COUNTY ROAD
RAILROAD
BRIDGE
TOWNS
SALT MARSH
COUNTY LINE
CROSS—SECTION LINE
WATER QUALITY NETWORK STATION
INTERMITTENT STREAM
SEEP AREA OR SALT PLAIN
RAYMOND
ARKANSAS
RIVER
STATION 767
T 21 S
T 22 S
T 23 S
BIG SALT MARSH
LITTLE SALT MARSH
A
A'
B
B'
F A S 554
F A S 39
F A S 653
281
AT & SF RR
HUDSON
RATTLESNAKE
CREEK
ST. JOHN
R 13 W
R 12 W
SCALE IN MILES
1 0 5

XXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXX

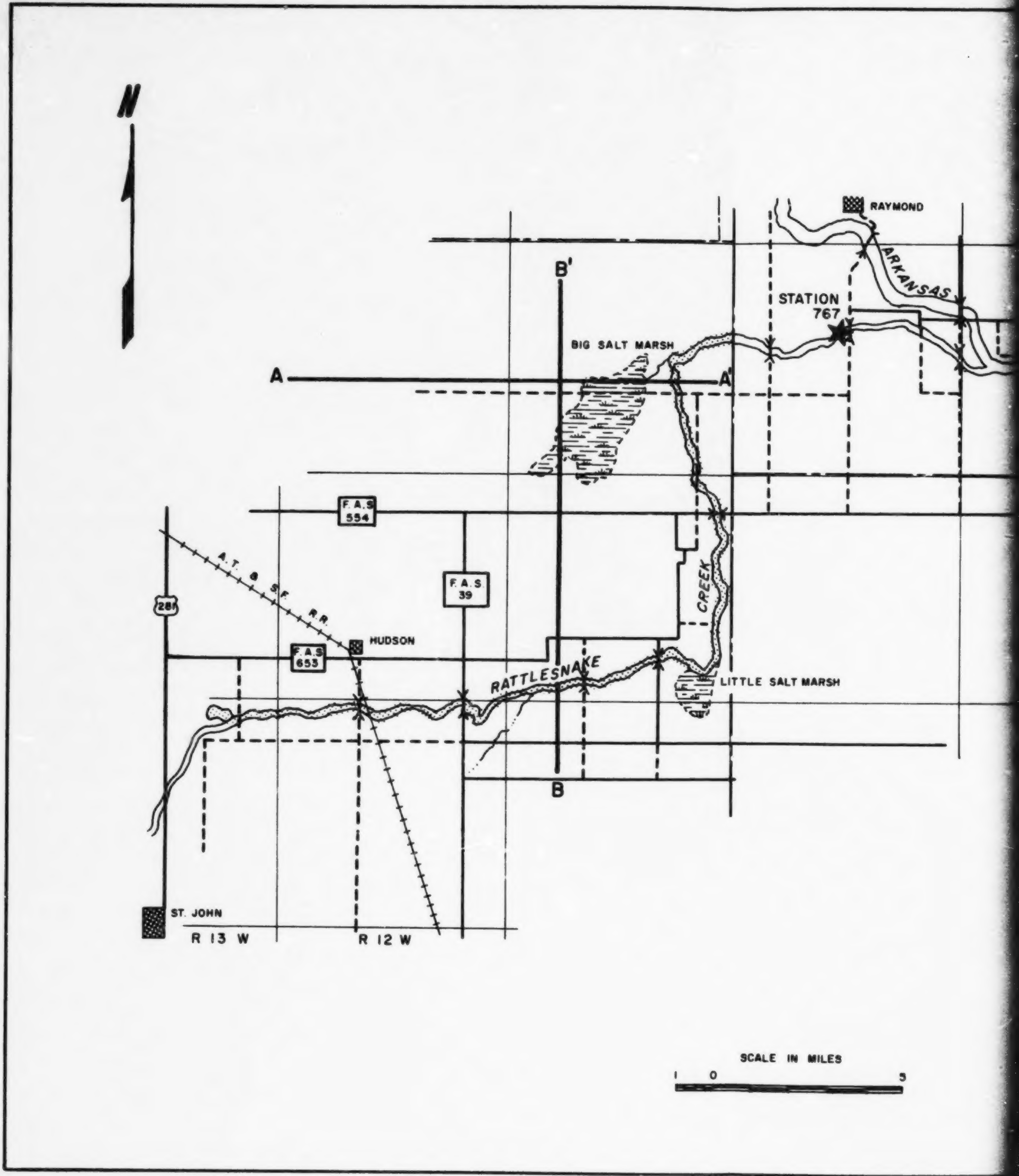
ARKANSAS - RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

RATTLESNAKE CREEK-AREA XII

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

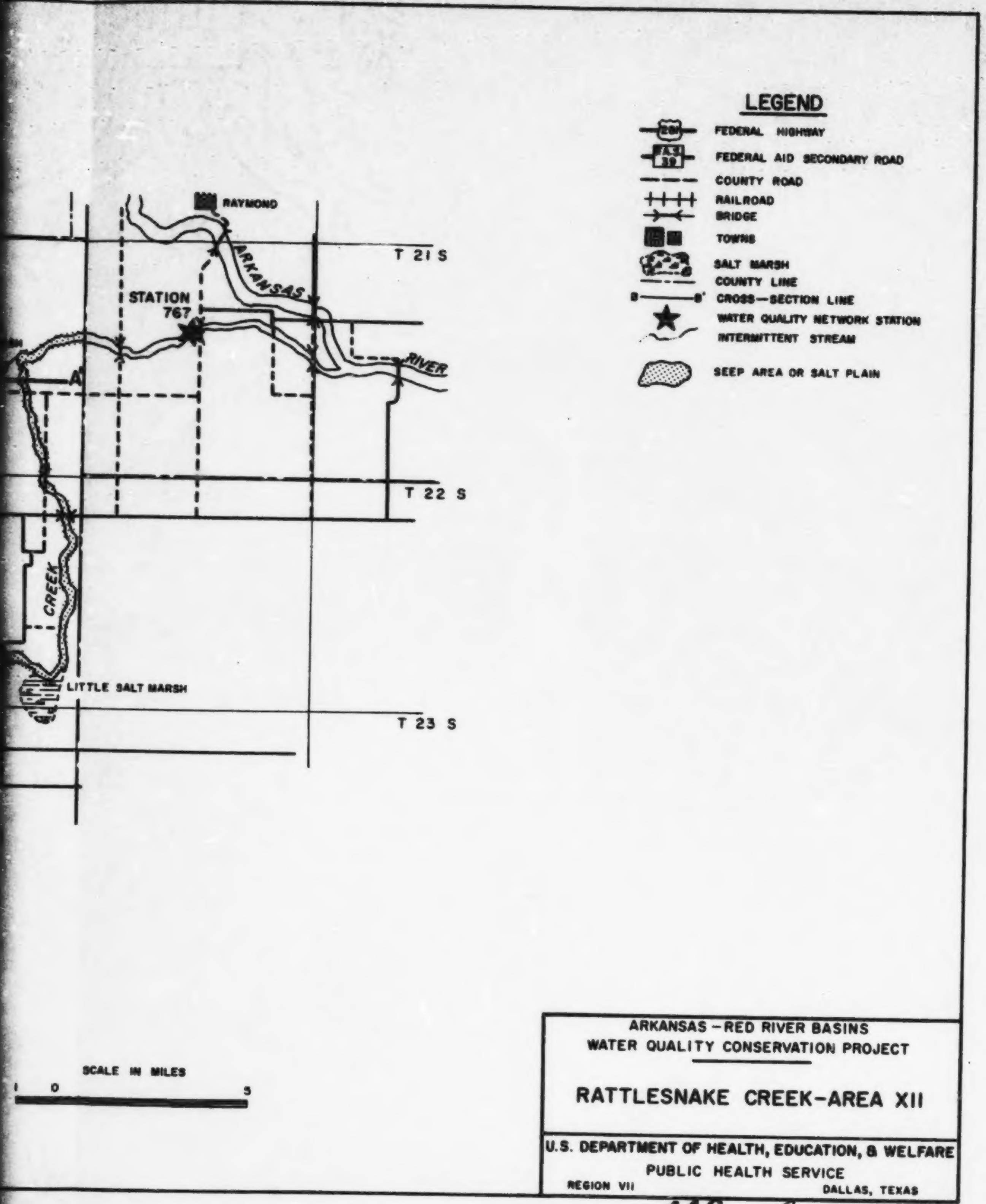
FIGURE IV-12

769-360 O 65 (Face p. IV 26)


N
RAYMOND
ARKANSAS
STATION 767
B'
BIG SALT MARSH
A
A'
F.A.S 554
F.A.S 39
CREEK
281
A.T. & S.F. R.R.
HUDSON
F.A.S 653
RATTLESNAKE
LITTLE SALT MARSH
B
ST. JOHN
R 13 W
R 12 W
SCALE IN MILES
1
0
5

A

769-560 O-65 (Face p. IV-26)

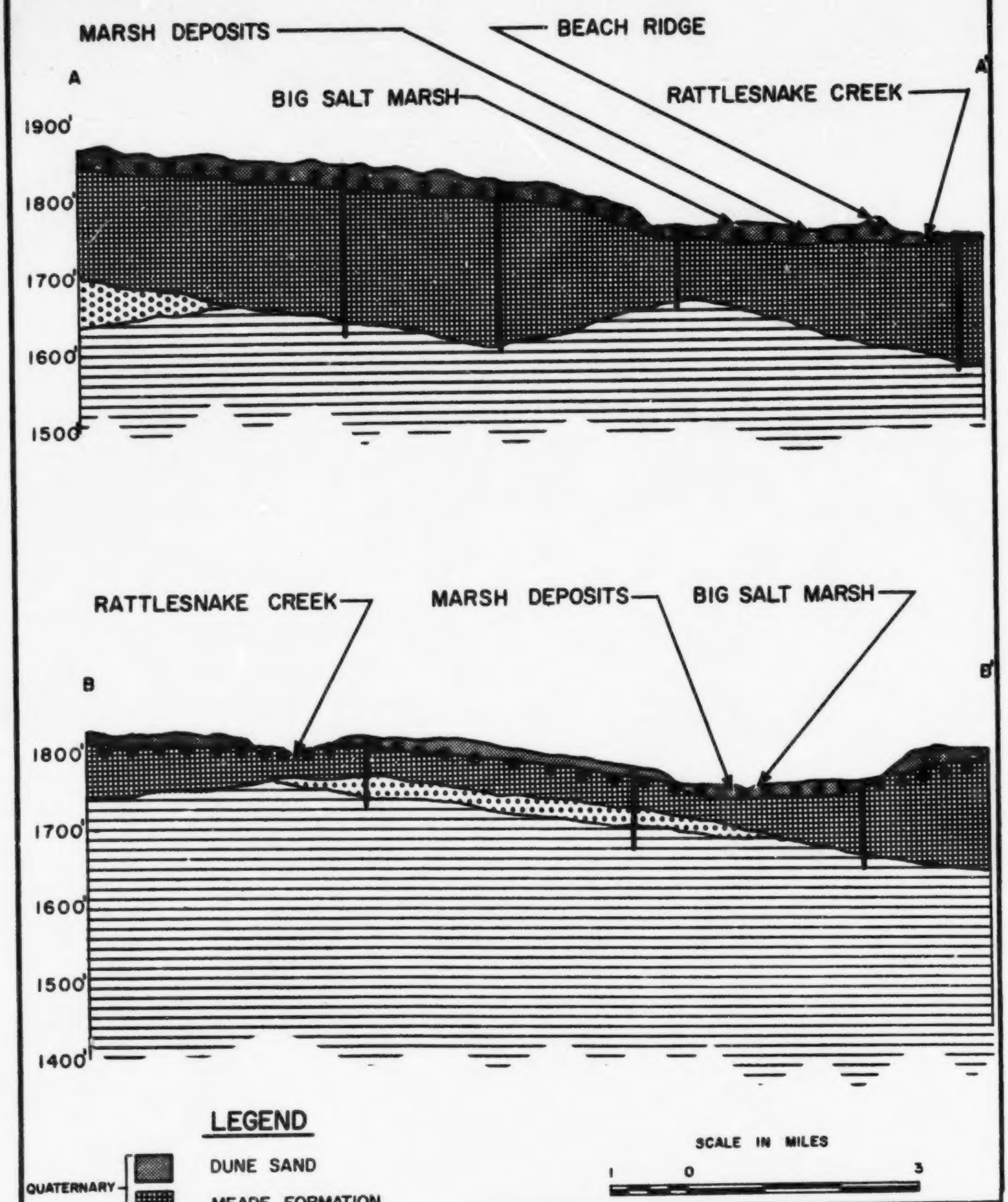

LEGEND
281
FEDERAL HIGHWAY
FAS 39
FEDERAL AID SECONDARY ROAD
COUNTY ROAD
RAILROAD
BRIDGE
TOWNS
SALT MARSH
COUNTY LINE
B B'
CROSS—SECTION LINE
WATER QUALITY NETWORK STATION
INTERMITTENT STREAM
SEEP AREA OR SALT PLAIN
RAYMOND
ARKANSAS
RIVER
STATION 767
A'
T 21 S
T 22 S
T 23 S
CREEK
LITTLE SALT MARSH
SCALE IN MILES
1 0 5

ARKANSAS – RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

RATTLESNAKE CREEK-AREA XII

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

B FIGURE IV-12


MARSH DEPOSITS
BEACH RIDGE
A
A'
BIG SALT MARSH
RATTLESNAKE CREEK
1900'
1800'
1700'
1600'
1500'
RATTLESNAKE CREEK
MARSH DEPOSITS
BIG SALT MARSH
B
B'
1800'
1700'
1600'
1500'
1400'
SCALE IN MILES
1
0
3
LEGEND
QUATERNARY
DUNE SAND
MEADE FORMATION
CRETACEOUS
CHEYENNE SANDSTONE
PERMIAN
PERMIAN REDBEDS
WATER TABLE
TEST HOLES

Adapted from Latta, 1950

ARKANSAS — RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

RATTLESNAKE CREEK — AREA XII
CROSS SECTIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-13

Ninnescah River

The Ninnescah River enters the Arkansas River at river mile 728, near Oxford, Sumner County, Kansas. The primary pollution areas are above the confluence of the North and South Forks of the Ninnescah River to the west of Cheney, Kansas (Figure IV-14).

Description of the Area

The North and South Forks of the Ninnescah River traverse the Ogallala sands and gravels of Tertiary age in the western third of their system; the Stone Corral Dolomite and Ninnescah Shale of Permian age in the middle third; and the Ninnescah Shale and Wellington Formation (both Permian) and Quaternary alluvial terraces in the eastern third.

Brine Emission

The only thorough investigations of this river system are those conducted by the Bureau of Reclamation, between June 1954 and February 1957. Results of these investigations reveal that, in general, waters of the North Fork are of acceptable quality, but those of the South Fork are not. For this reason, the majority of work has been restricted to the South Fork.

The source of salt pollution is restricted to an 8 mile stretch of the South Fork from a mile west of Cairo to north of Cunningham. This reach is a general seep area that includes ponds and sloughs just north of Cairo. Water quality is poor in these low-lying sloughs, whereas ground water samples at higher elevations are of good quality. This is attributed to the leaching of salt by ground water in the underlying Ninnescah Shale and Wellington Formation and its movement to the surface in the vicinity of the ponds and sloughs. Most of the salt pollution enters the river by seepage, the poorer quality waters entering the river from the north.

Oilfield pollution in the vicinity of Skellyville is considered negligible even though some salt encrustment is found around the stripper wells in the area. This is substantiated by the sodium to chloride ratio which averages about 0.65 - a value that is too high for oilfield brine.

Salt Load

Average measurements for waters of the Ninnescah River system over a 3-year period indicate a flow of 300 cubic feet per second and a chloride load of 250 tons per day. About two-thirds of the salt load is believed to originate from the South Fork and one-third from the North Fork.

Salt Creek of Prairie Dog Town Fork of Red River - Area XIV

The area is located in the northwestern quarter of Childress County, Texas. Salt Creek has its confluence with Prairie Dog Town Fork of Red River at river mile 1,063 about 2 miles west of the U.S. Highways 62-83 river bridge north of Childress, Texas. The source area of salt pollution extends from the confluence upstream about 5 miles (Figure IV-15).

Description of the Area

Salt Creek has cut its valley about 50 to 75 feet below the surrounding upland surface. Sandstone, dolomite, and gypsum of the Whitehorse Group crop out on the high ridges in the area and on the uplands to the northwest. In the salt source area, the creek flows over the Dog Creek Shale and Blaine Gypsum Formations.

The Permian surface rocks in this area are weathered and fractured and appear favorable for ground water recharge. The shale is fairly impervious, but most shales in the area are highly weathered and fractured near the surface. It is probable that salt is being leached out of the Dog Creek and Blaine Formations by percolating ground waters. Salt springs and seeps have not been located. Field measurements of stream discharge indicate a gradual increase in flow along the course of the stream. This is attributed in part to infiltration of salt water into the stream from subsurface formations underlying the stream course.

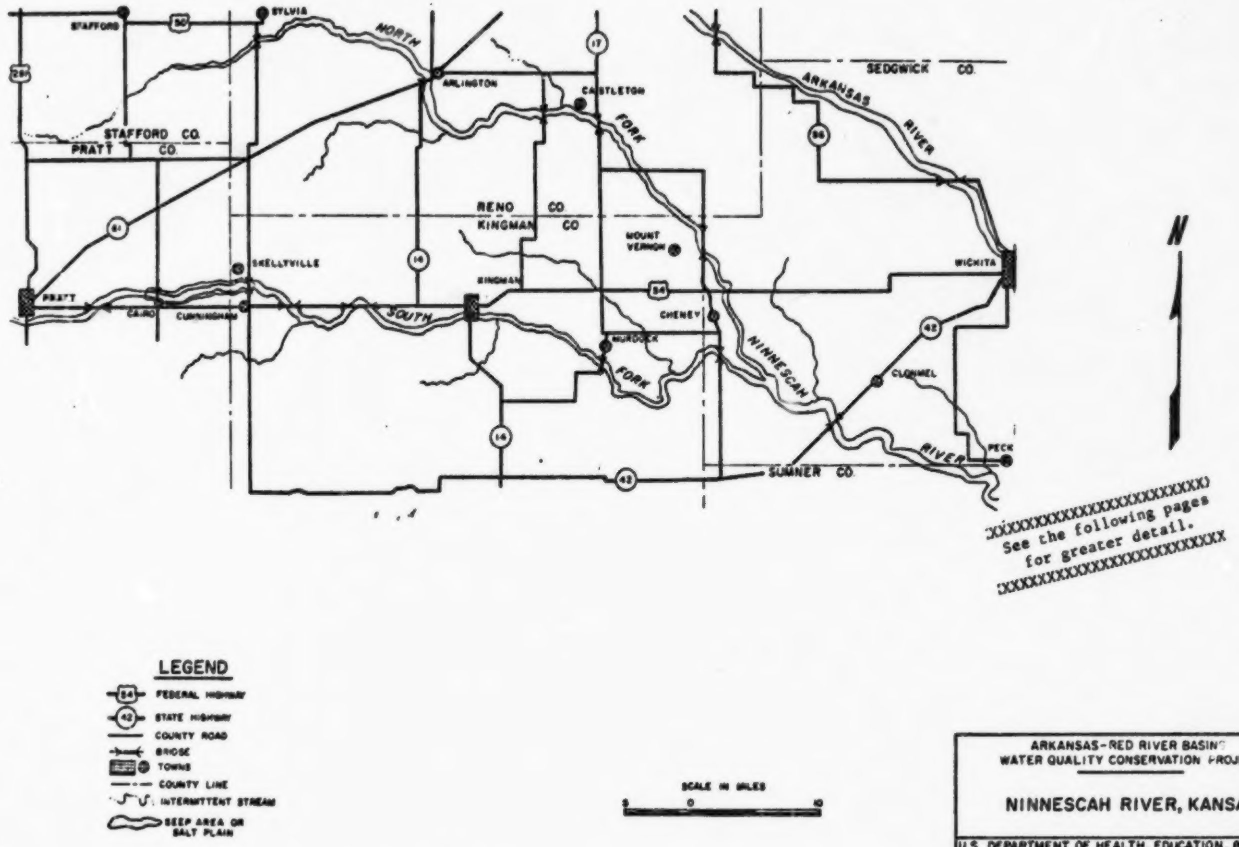
A salt flat covering about 80 acres is located just above the Salt Creek confluence with Prairie Dog Town Fork. This is an overflow area for Salt Creek, and during high water becomes brine saturated. No salt pollution is known to exist on East Salt Creek, the only major tributary to Salt Creek in the salt source area.

Brine Emission

The major area of salt pollution is about one mile above the confluence and is attributed to springs and seeps within the flow channel.

A minor tributary entering Salt Creek from the west and about one mile upstream from the county road bridge is also a source of salt water. Although the flow from this source is only 0.15 cubic foot per second, the chloride concentration reaches 31,000 mg/1. This flow seeps from beneath ledges of Dog Creek Shale. Upstream from this tributary, the chloride content in Salt Creek decreases to about 50 mg/1.

Analyses of the area water are given on Table IV-11.


STAFFORD
SYLVIA
NORTH
ARLINGTON
CASTLETON
FORK
SEDGWICK CO.
ARKANSAS
RIVER
STAFFORD CO.
PRATT CO.
RENO CO
KINGMAN CO
MOUNT VERNON
WICHITA
N
SKELLYVILLE
KINGMAN
PRATT
CAIRO
CUNNINGHAM
SOUTH
CHENEY
MURDOCK
FORK
NINNESCAH
CLONMEL
RIVER
PECK
SUMNER CO.
50
281
61
17
96
14
54
42
LEGEND
FEDERAL HIGHWAY
STATE HIGHWAY
COUNTY ROAD
BRIDGE
TOWNS
COUNTY LINE
INTERMITTENT STREAM
SEEP AREA OR SALT PLAIN
SCALE IN MILES
5
0
10

XXXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXXX

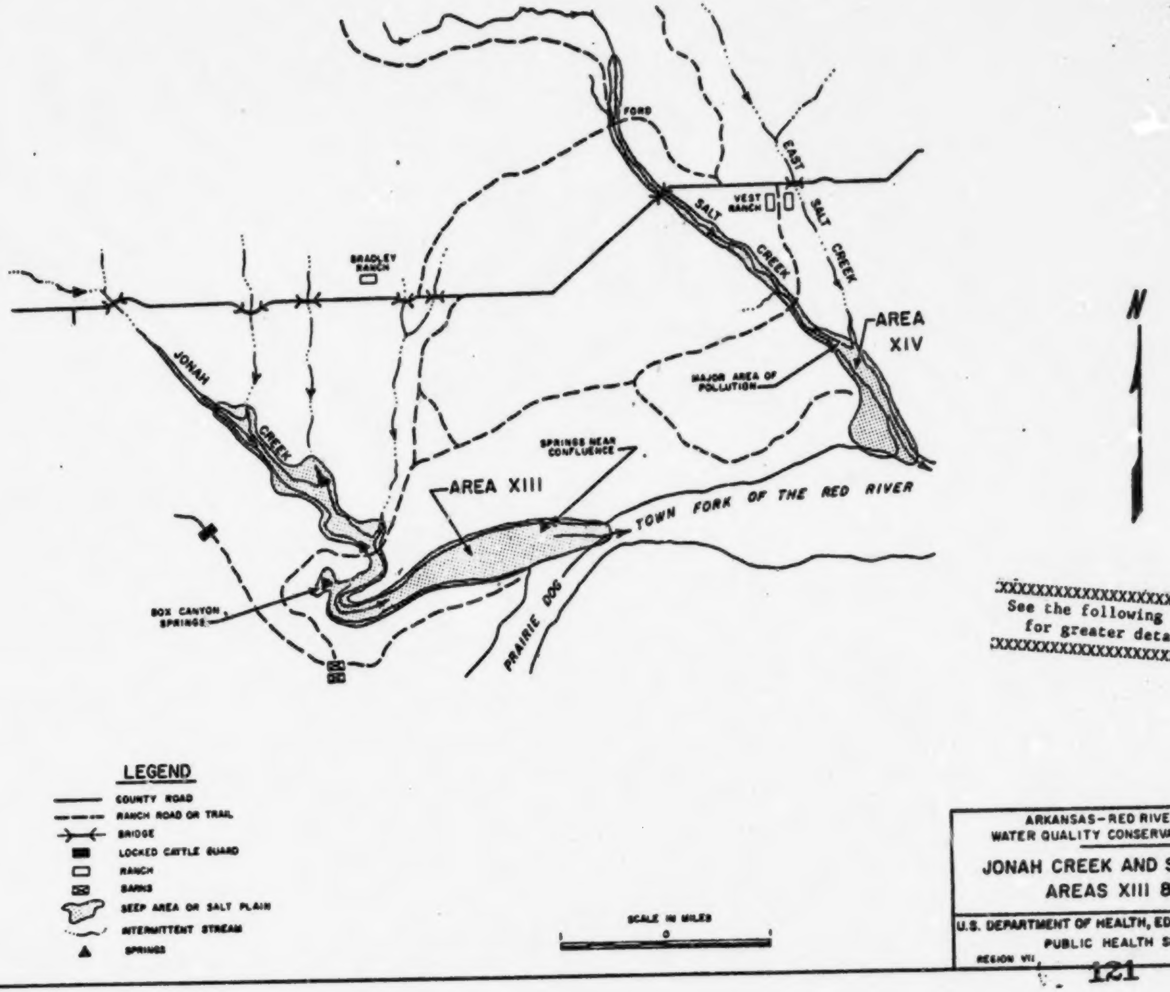
ARKANSAS-RED RIVER BASIN
WATER QUALITY CONSERVATION PROJECT

NINNESCAH RIVER, KANSAS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-14

769-560 O-65 (Face p. IV 28) No. 1


FORD
EAST SALT CREEK
VEST RANCH
SALT CREEK
BRADLEY RANCH
AREA XIV
MAJOR AREA OF POLLUTION
JONAH CREEK
SPRINGS NEAR CONFLUENCE
AREA XIII
TOWN FORK OF THE RED RIVER
BOX CANYON SPRINGS
PRAIRIE DOG
N
LEGEND
COUNTY ROAD
RANCH ROAD OR TRAIL
BRIDGE
LOCKED CATTLE GUARD
RANCH
BARNS
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
SPRINGS
SCALE IN MILES
1
0
1

XXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXXX

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

JONAH CREEK AND SALT CREEK
AREAS XIII & XIV

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-15

Table IV-11

Chemical Analyses of Natural Brines
Salt Creek - Area XIV

	Collection Point	
	Lower Ford	Creek at Confluence
Date Collected	9-5-62	9-5-62
pH	7.4	7.5
Spec. cond. 25°C, micromhos/cm	19,500	34,500
Total alkalinity ($CaCO_3$)	86	72
Total hardness ($CaCO_3$)	3,400	5,000
Dissolved Solids	16,300	50,800
Calcium (Ca)	1,042	1,600
Magnesium (Mg)	213	243
Sodium (Na)	4,100	15,000
Potassium (K)	20	20
Sulfate (SO_4)	2,700	3,900
Chloride (Cl)	7,000	26,500
Silica (SiO_2)	11	10
Boron (B)	0.7	1.7
Fluoride (F)	2.0	4.0
Turbidity, Jackson Units	25	25

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

Several water wells in the Salt Creek basin are too highly mineralized for human consumption, and several others are even too high in chlorides to be used for stock water.

Salt Load

Computations based on available data indicate that Salt Creek is contributing an average of 150 tons per day of chloride and 20 tons per day of sulfate to the Prairie Dog Town Fork of Red River.

Jonah Creek of Prairie Dog Town Fork of Red River - Area XIII

This area is located in the northwestern quarter of Childress County, Texas. Jonah Creek has its confluence with Prairie Dog Town Fork of Red River at river mile 1,068, about 7 miles west of the U.S. Highways 62-83 river bridge north of Childress, Texas. The salt spring and seep area extends from the lowest springs on the river flood plain about 6 stream miles upstream along the creek to a point about one-half mile below the county road bridge (Figure IV-15).

Description of the Area

Jonah Creek heads near Memphis, Texas and flows in a southeasterly direction to its confluence with Prairie Dog Town Fork of Red River. The stream is perennial along the lower 5 or 6 miles of its course where the first salt springs and seeps occur. The salt water usually appears as seeps in the sandy alluvium at, or very near, an outcrop of fractured, finely-crystalline, impure dolomite in the stream channel and from lateral holes in the dolomite along the edges of the stream. The stream has cut a valley about 75 feet below the surrounding upland surface. Sandstone, dolomite, and gypsum of the Whitehorse Group crop out on the high ridges in the area and on the uplands to the northwest. In the salt source area, the creek flows over the Dog Creek Shale and Blaine Gypsum Formations.

The middle 2 or 3 miles of the salt source area have salt plains that are from 2 to 5 feet higher in elevation than the creekbed. These plains, 5 or 6 in number, are about 20 to 50 acres in size and are located on both sides of the stream. During dry weather, a thick salt encrustment forms upon the plains. The warped nature of the dolomite in the area of the plains is associated with subsidence features.

Surface materials of the surrounding uplands are favorable for ground water recharge. The exposed gypsum is fractured and contains solution openings. Water is readily absorbed and transmitted through these rocks and through the fractured dolomite which provides passages for the salt water to escape to the surface along the creek.

Brine Emission

Salt springs and seeps occur at numerous places along Jonah Creek throughout the source area with the 3 major visible sources here described.

1. The lowest source occurs at the river confluence on the river flood plain. Here a number of small springs flow out of lateral holes in a bed of shale about 4 feet thick, and confined between 2 dolomite beds. The spring holes are close to the water level of the creek and are from 3 to 10 inches in diameter. Some water enters directly into the stream flow bed, as is evidenced by bubbling sand and density currents. These springs contribute a flow of approximately 0.7 cubic foot per second and have a chloride concentration of 39,000 mg/l.

2. Another source is in a box canyon located about one mile downstream from the ranch road crossing. The canyon floor is composed of fractured dolomite and contains numerous small springs. Much of the flow from the springs evaporates in the canyon and leaves a thick salt deposit. When local rains occur, this salt is taken into solution and carried into the creek.

3. Other salt water springs and seeps occur several hundred feet above the ranch road crossing where the creek flows over an outcrop of dolomite. The seeps are in the sand alluvium, and the springs flow from cracks and holes in the dolomite. One spring is submerged in the flow channel of the creek. Its flow bubbles up about 2 or 3 inches above the water surface. It emerges from a hole in the dolomite about 3 inches in diameter and has a flow of about 0.5 cfs.

Analyses of the area water are given on Table IV-12.

Salt Load

The salt load from Jonah Creek has been determined from streamflow measurements and grab samples taken between October 1961 and April 1962. The springs in the Jonah Creek salt source area have chloride concentrations that range between 25,000 and 39,000 mg/l. The flow from the springs has been relatively stable during the period of investigation. The creek appears to contribute an average salt load of 450 tons per day of chlorides and 30 tons per day of sulfate. During rainy periods, flushouts from the salt

Table IV-12

Chemical Analyses of Natural Brines
Jonah Creek - Area XIII

	Collection Point		
	Bubbling Spring	Spring at Confluence	Creek at Confluence
Date Collected	9-5-62	9-5-62	9-5-62
pH	7.1	7.1	7.1
Spec. cond. 25°C, micromhos/cm	70,000	48,000	45,000
Total alkalinity ($CaCO_3$)	90	98	90
Total Hardness ($CaCO_3$)	5,600	5,600	5,600
Dissolved solids	78,000	71,800	63,900
Calcium (Ca)	1,760	1,680	1,600
Magnesium (Mg)	292	340	388
Sodium (Na)	24,000	22,000	20,000
Potassium (K)	85	83	78
Sulfate (SO_4)	5,100	5,100	4,600
Chloride (Cl)	40,800	39,000	34,000
Silica (SiO_2)	11	12	9.2
Boron (B)	3.0	2.5	2.3
Fluoride (F)	10	15	15
Turbidity, Jackson units	25	25	25

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

plains can increase the load appreciably. One flow measurement and sample at the confluence, immediately after a local rain, showed a flow of 8.8 cfs and a chloride concentration of 31,000 mg/l. This is a chloride load of 735 tons per day.

There are several water wells in the Jonah Creek basin, but, in general, those between the county road and the river are too highly mineralized for human consumption; and several are even too high in chloride content to be used for stock water.

Salt Spring at Estelline, Texas - Area V

This spring is located on the flood plain of the Prairie Dog Town Fork of the Red River at about river mile 1,073. The spring is on the south side of the river, approximately 3 miles downstream from the bridge on U.S. Highway 287, and about three-fourths of a mile east of the town of Estelline, Hall County, Texas (Figure IV-16).

Description of the Area

Salt water in this area is brought to the surface through one large spring, a deep sinkhole created by the collapse of rock beds into solution cavities in the underlying gypsum of the Blaine Formation. Other sinkholes are present on the alluvial plain nearby but are choked with silt and clay fill at the bottom. Some sinks contain salty water, indicating that salt water seeps upward through the rock debris, filling the lower part of the sink.

The spring is on the south edge of the alluvial plain of the Prairie Dog Town Fork, which is about one mile wide in this vicinity. The river has intermittent flow along this reach of the stream and is typically braided. For about 3 miles downstream from the U.S. Highway 287 bridge, the south bank of the river cuts into vegetation-covered sand dunes. These dunes form a natural levee which prevents the river from overflowing upon the low plain where the spring is located. The riverbed immediately north of the spring is about 5 feet higher in elevation than the spring surface. Bedrock south of the river is obscured in most places by the alluvial cover, but immediately south of the spring at a point near the edge of the alluvial plain, gypsiferous Dog Creek Shale outcrops from beneath sand dunes. In the area north of the river, there are extensive outcrops of gypsiferous shale and gypsum members of the Whitehorse Group. Regional studies indicate that salt-bearing deposits occur at relatively high elevations under the uplands, both north and south of the river.

Core hole V-1 was drilled 1½ miles southwest of the spring to a total depth of 280 feet without penetrating saltbeds. The shale interbedded with gypsum and anhydrite from a depth of 206 feet to the bottom of the hole had a salty taste. These beds probably are in the Blaine Gypsum, or its equivalent.

Brine Emission

The spring surface has a diameter of about 60 feet. Skin-diving investigations revealed that the throat of the spring narrows to about 20-25 feet at a depth of 20 feet but opens into a large cavern between depth of 60 and 125 feet.

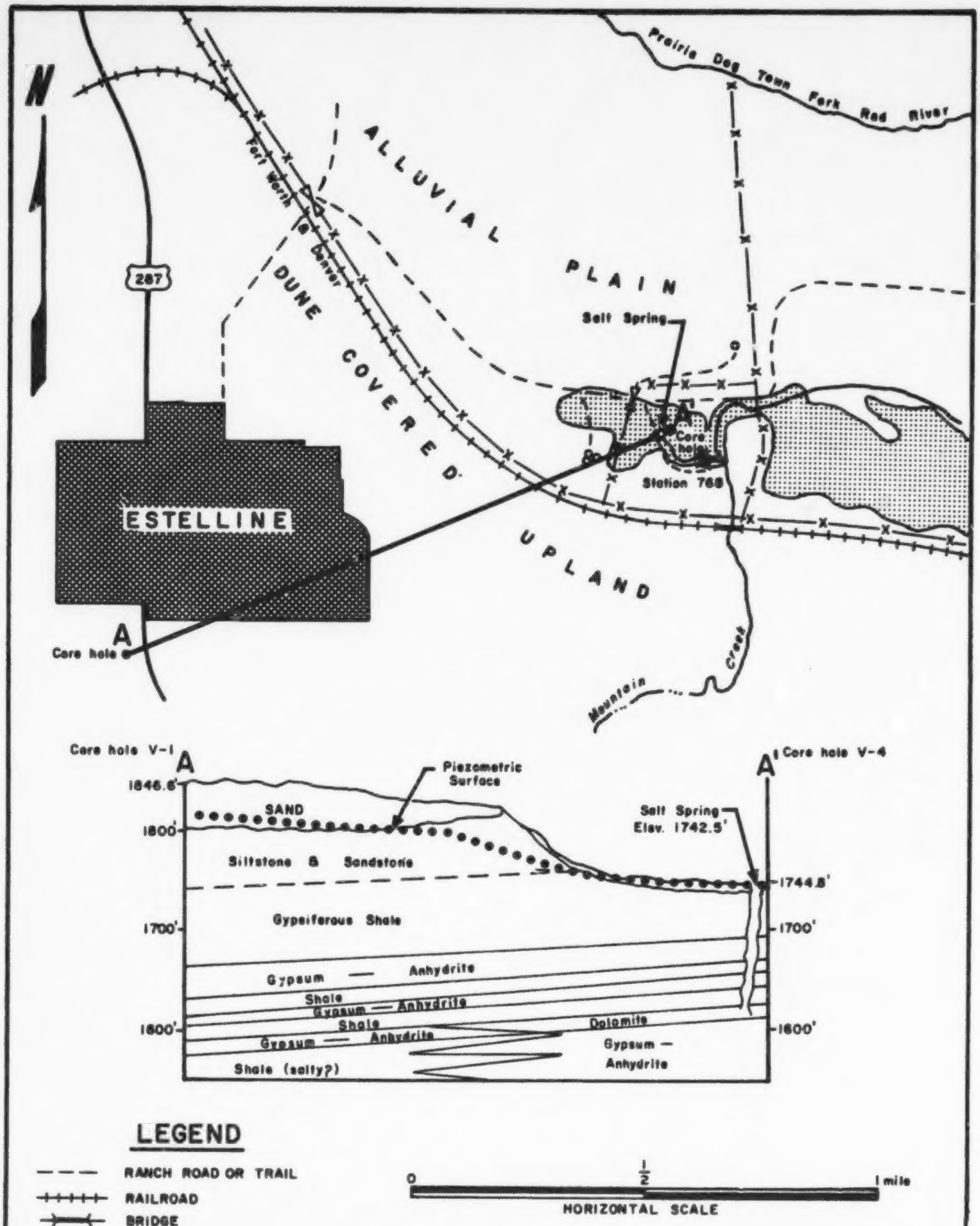
The quality of the water in the spring remains about the same throughout the year with a chloride concentration of approximately 25,000 mg/l. Analyses of the spring water are given on Table IV-13. Flow measurements of the spring discharge average approximately 5.7 cfs.

Flow data from October 1960 to May 1962 indicate an increase in flow from the fall season to early spring, and a decrease in flow from spring to fall. The period of decreasing flow corresponds to the irrigating season in the adjacent area.

In October 1961, the Army Corps of Engineers lowered the surface level of the spring by approximately 6 feet, using a pump discharge of 11 cfs. There was no change in the chloride concentration of the water during or after the test, and the discharge continued the same after the test. In May 1961, the same group produced a head of approximately 2 feet in 4½ hours by means of a ring dike of alluvial sand. The head was maintained for about 24 hours. During this period, the normal spring discharge was decreased by about one-half.

Salt Load

The chloride and sulfate load originating from this spring has been determined to be 375 and 60 tons per day, respectively.


N
287
ESTELLINE
A
Core hole
Fort Worth & Denver
ALLUVIAL PLAIN
DUNE COVERED UPLAND
Prairie Dog Town Fork Red River
Salt Spring
Core hole
Station 768
Mountain Creek
Core hole V-1
A
1846.6'
1800'
1700'
1600'
SAND
Piezometric Surface
Siltstone & Sandstone
Gypsiferous Shale
Gypsum — Anhydrite
Shale
Gypsum — Anhydrite
Shale
Gypsum — Anhydrite
Shale (salty?)
Dolomite
Gypsum — Anhydrite
A'
Core hole V-4
Salt Spring Elev. 1742.5'
1744.8'
1700'
1600'
0
½
1 mile
HORIZONTAL SCALE

LEGEND

- - - RANCH ROAD OR TRAIL
+++++ RAILROAD
BRIDGE
GATE
—X—X— FENCE
○ SINKHOLES & SPRING
SEEP AREA or SALT PLAIN
★ WATER QUALITY NETWORK STATION

NOTE: Core hole designation by Corps of Engineers.

ARKANSAS—RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

SALT SPRING NEAR ESTELLINE, TEXAS
AREA V
MAP AND INTERPRETATIVE CROSS SECTION

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-16

Table IV-13

Chemical Analyses of Natural Brines
Salt Spring - Estelline, Texas - Area V

	Collection Point		
	Channel Flow	Channel Flow	Channel Flow
Date collected	4-25-60	8-5-60	9-15-60
pH	7.4	7.9	7.7
Specific Gravity, 20°C	1.0289	1.0317	1.0280
Spec. cond. 25°C, micromhos/cm	63,000	60,000	58,000
Total alkalinity ($CaCO_3$)	120	106	112
Total hardness ($CaCO_3$)	5,600	5,600	6,000
Dissolved solids	50,900	48,000	44,400
Calcium (Ca)	1,440	1,600	1,520
Magnesium (Mg)	486	390	535
Sodium (Na)	18,000	15,000	16,500
Potassium (K)	110	100	60
Sulfate (SO_4)	4,700	4,300	3,700
Chloride (Cl)	25,250	25,500	25,700
Iron (Fe)	0	0	0
Silica (SiO_2)	13.4	12.4	
	1.9	2.0	2.0
Boron (B)	2.5	2.9	1.4
Fluoride (F)	20	6	30
Iodine (I)			
Bromine (Br)	20	6	30
Manganese (Mn)	0	0	0

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

Little Red River of Prairie Dog Town Fork of Red River - Area XV

The area is in west-central Hall County and extreme east-central Briscoe County, Texas. The confluence of Little Red River is at river mile 1,090 of Red River. The area extends west from the confluence about 20 miles to the major salt source in the canyons immediately west of the Texas State Highway 70 bridge and near the Hall-Briscoe County line. (Fig.IV-17)

Description of the Area

The surface outcrops of this area consist of, in descending order, the Quartermaster Formation, Cloud Chief Gypsum, and Whitehorse Sandstone of late Permian age. The river, in its upper reaches, has cut its valley about 300 feet below the surrounding upland surfaces. Bedrock for most of the Little Red River is the Whitehorse Sandstone, which is a red, fine-grained sandstone with irregular beds of dolomite and gypsum.

Three canyons exist above State Highway 70 near the county line. The north and south canyons have salt plains situated near their confluences, while the middle canyon does not. The canyons have high steep walls which, during dry weather, exhibit a thin salt encrustment on the lower 4 or 5 feet. The canyon floors both have a thick salt encrustment.

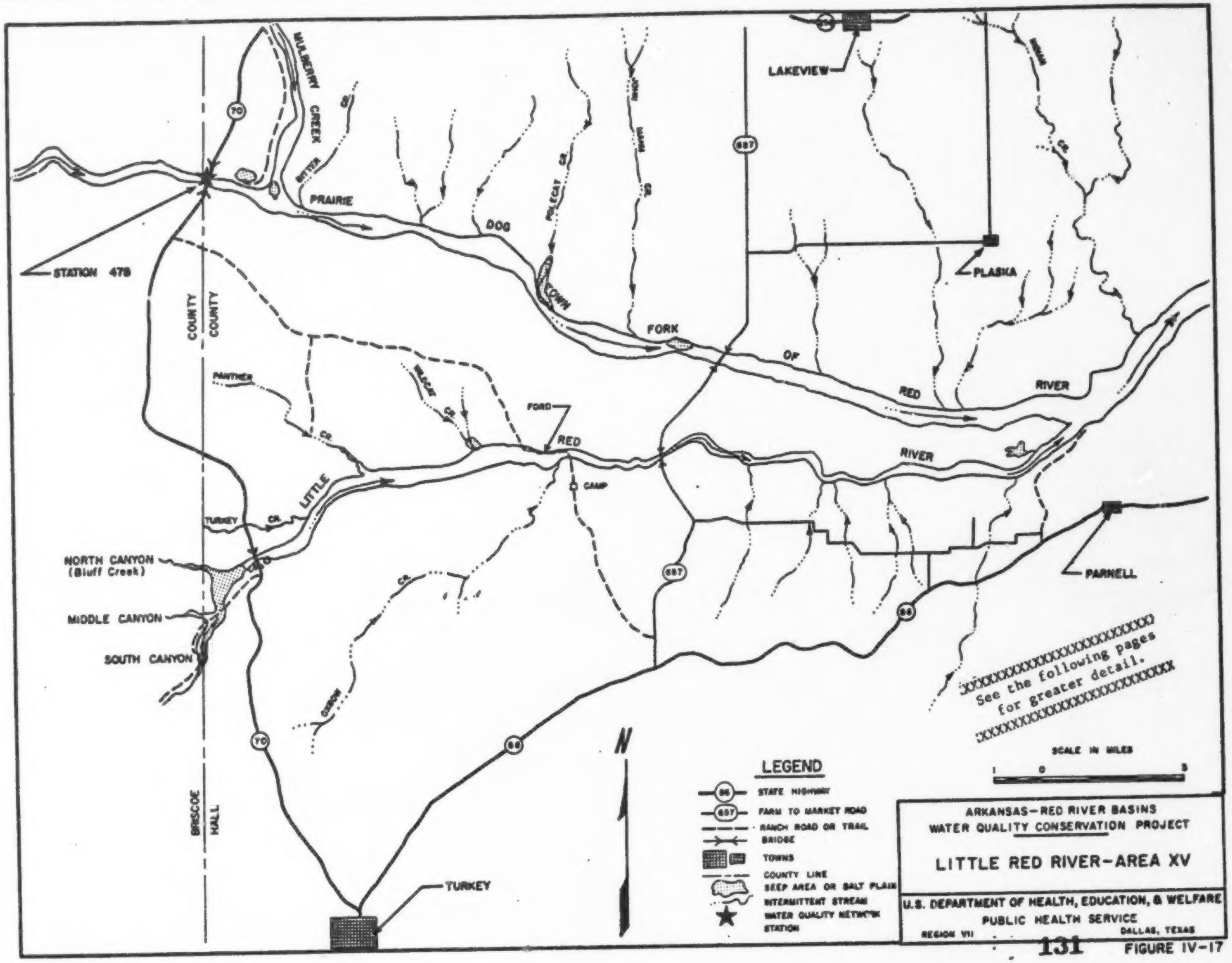
Density currents observed in the small flow which meanders over the plain are evidence of percolating ground water making its way to the surface on the plain.

The areal extent of the south and north plains are 300 acres and 50 acres, respectively.

Small salt plains exist on both sides of State Highway 70, away from the river channel. The small plain just west of the highway results from high flow storage, while the east plain contains a small box canyon seepage source. This east salt plain extends downstream from the mouth of the canyon for several hundred yards.

The river flows in an easterly direction and becomes a perennial stream in the lower 10 miles of its length. Flow is nearly always present upon the salt plains located near the Hall-Briscoe County line, but during the dry seasons the flow disappears into the alluvium shortly after leaving the plains. The flow originates, in part, in the canyons above the salt plains and becomes progressively higher in chlorides as it crosses the plains.

Because the flow in the upper reaches of this river is intermittent, salt storage takes place on and in the riverbed alluvium during dry periods.


MULBERRY CREEK
BITTER CR.
PRAIRIE
DOG
TOWN
FORK
OF
RED
RIVER
POLECAT CR.
JOHN MANN CR.
INDIAN CR.
LAKEVIEW
PLASKA
STATION 478
COUNTY
COUNTY
BRISCOE
HALL
PANTHER
CR.
WILDCAT
CR.
FORD
RED
RIVER
CAMP
LITTLE
TURKEY
CR.
NORTH CANYON
(Bluff Creek)
MIDDLE CANYON
SOUTH CANYON
CR.
TURKEY
PARNELL
70
657
86
N
SCALE IN MILES
1
0
3
LEGEND
STATE HIGHWAY
FARM TO MARKET ROAD
RANCH ROAD OR TRAIL
BRIDGE
TOWNS
COUNTY LINE
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
WATER QUALITY NETWORK STATION

XXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXX

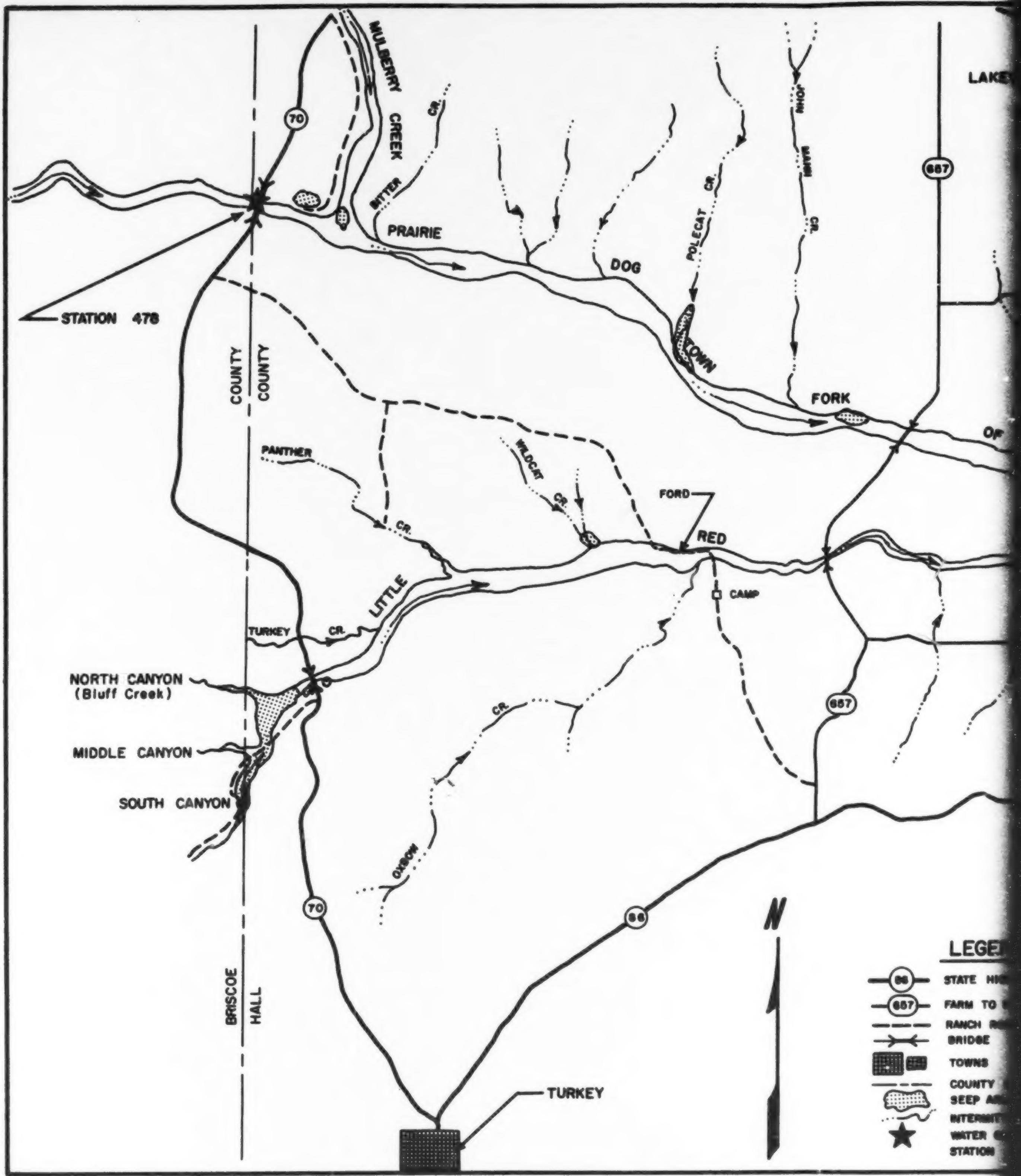
ARKANSAS—RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

LITTLE RED RIVER-AREA XV

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

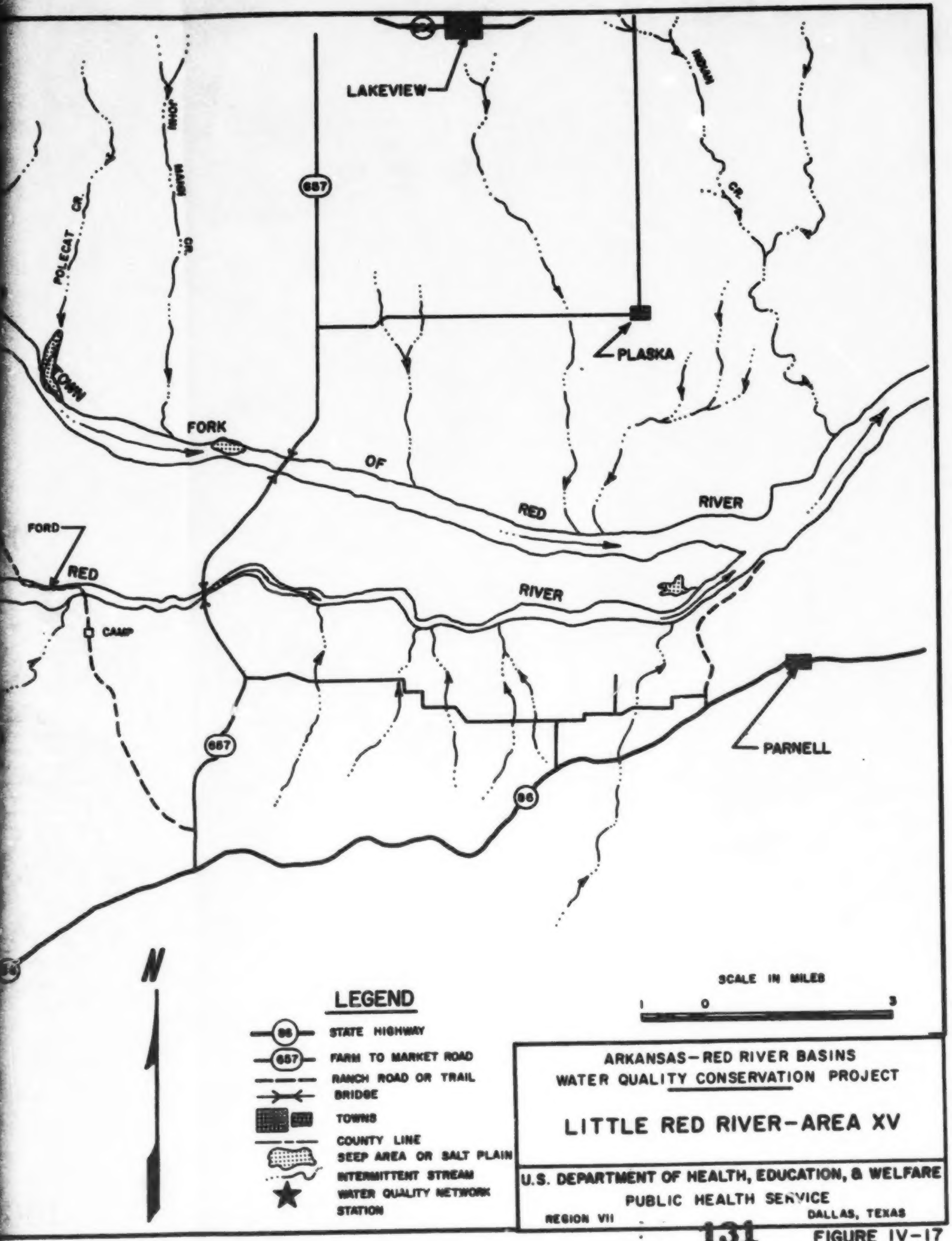
FIGURE IV-17

769 540 O 65 (Face p. IV 36)


MULBERRY CREEK
BITTER CR.
70
STATION 478
PRAIRIE
DOG
TOWN
FORK
OF
POLECAT CR.
JOHN MAHI CR.
657
LAKE
COUNTY
COUNTY
PANTHER CR.
WILDCAT CR.
FORD
RED
CAMP
LITTLE
TURKEY CR.
NORTH CANYON
(Bluff Creek)
MIDDLE CANYON
SOUTH CANYON
CR.
OXBOW
86
N
BRISCOE
HALL
TURKEY
LEGE
STATE HI
FARM TO
RANCH RO
BRIDGE
TOWNS
COUNTY
SEEP A
INTERMIT
WATER
STATION

A

769-560 O-65 (Face p. IV-36)


LAKEVIEW
JOHN MANN CR.
POLECAT CR.
INDIAN CR.
687
PLASKA
TOWN
FORK OF RED RIVER
FORD
RED RIVER
CAMP
687
PARNELL
96
96
N
SCALE IN MILES
1 0 3
LEGEND
96 STATE HIGHWAY
657 FARM TO MARKET ROAD
RANCH ROAD OR TRAIL
BRIDGE
TOWNS
COUNTY LINE
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
WATER QUALITY NETWORK STATION

ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

LITTLE RED RIVER–AREA XV

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-17

B

Brine Emission

The primary area of salt contamination of the stream appears to be the north and south canyons above Highway 70. Although the flow is intermittent at the highway crossing, the small amounts that pass are very high in chlorides and amount to a substantial salt load.

About 6 miles downstream from the State Highway 70 bridge, Wildcat Creek, a tributary from the north, produces small quantities of salt. A storage plain extending upstream for approximately three-fourths mile exists at the confluence of this creek with Little Red River. Upstream from the confluence, pools of water having a chloride ion concentration of about 5,700 milligrams per liter have been found.

When investigated, some flow always existed at Farm to Market Road 657. The chloride ion concentration at this point remained relatively stable at about 20,000 mg/l.

The average flow at the confluence, excluding flush flows, is about 1.6 cfs, with a chloride ion concentration of about 14,000 mg/l. One tributary, about 1½ miles upstream from the confluence, contributes a flow of about 0.1 cfs. This water is approximately the same quality as the river water.

About one-half mile above the confluence to the north is a slough which covers an area of about 10 acres. This slough which is situated on the alluvium between the Prairie Dog Town Fork of Red River and Little Red River is fed by very small seeps and springs around its perimeter. A flow of 0.2 cfs and concentration of 12,000 mg/l chloride ions have been found during each investigation of this slough.

The river averages about 100 feet wide with cut banks about 8 feet high in the lower 10 or 12 miles. In the lower 6 miles of the stream, there is a gradual increase in flow.

Ground water samples reveal that the chloride concentrations of subsurface waters are generally equal to, or greater than, those of the surface water.

Analyses of the area water are given on Table IV-14.

Salt Load

The average chloride and sulfate loads from this river, including estimates of flush flows, are approximately 150 and 10 tons per day, respectively.

Table IV-14

Chemical Analyses of Natural Brines
Little Red River - Area XV

	Collection Point	
	South Canyon	At FM Highway 657
Date Collected	9-6-62	9-6-62
pH	7.7	7.5
Spec. cond. 25°C, micromhos/cm	81,000	61,000
Total alkalinity ($CaCO_3$)	88	116
Total hardness ($CaCO_3$)	8,200	5,400
Dissolved solids	151,000	58,000
Calcium (Ca)	1,760	1,400
Magnesium (Mg)	923	440
Sodium (Na)	52,000	18,000
Potassium (K)	66	92
Sulfate (SO_4)	5,600	4,500
Chloride (Cl)	88,000	31,000
Silica (SiO_2)	11	13
Boron (B)	11	3.3
Fluoride (F)	10	15
Turbidity, Jackson units	25	25

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

Prairie Dog Town Fork of Red River West of Texas State Highway 70 - Area XI

This natural salt source area includes the Prairie Dog Town Fork of Red River and its tributaries between Texas State Highway 70 and Dry Creek, which is about 5 miles west of Texas State Highway 284 in the southwestern quarter of Armstrong County, Texas. The State Highway 70 river bridge is at about river mile 1,110 of Red River (Figure IV-18).

Description of the Area

Throughout this reach of river, the flow is usually low or intermittent and, within a few miles, may vary greatly in chloride ion concentration. During dry periods, only a few of the tributaries contribute flow. There is an almost continuous storage of salt on and in the alluvial sands of the river. Small individual salt sources have been identified at different points along the stream, however, the true magnitude of these sources was not determined due to low flows that occurred during the investigation.

The Ogallala of Pliocene age, is the bedrock on the high plains or caprock. It retains a high percentage of the area's precipitation, resulting in little surface runoff and slow moving ground water. The surface topography upon the caprock is characterized by numerous natural ponds and lakes and very few streams.

Underlying the Ogallala Formation is the Dockum Group of Triassic age which consists of red sandstone and shales. The Dockum is usually exposed at the top of the canyon walls and in some places is a ledge former.

Below the Dockum Group is the Double Mountain Group which consists of red, fine-grained sandstones, gypsiferous shales, thin dolomites, and irregular beds of gypsum.

The Prairie Dog Town Fork of Red River has cut its valley several hundred feet into the surrounding uplands forming the Palo Duro Canyon in its upper reaches. Valley bedrock is composed of the Quartermaster Formation, Cloud Chief Gypsum, and Whitehorse Sandstone in descending order. The Whitehorse Sandstone is reported to contain thick beds of salt locally to the south. It is also reported that the Cloud Chief may contain salt in the basal part.

Brine Emission

Proceeding west from the eastern limit of this area, the first salt source encountered is heavy salt encrustment forming a salt flat covering about 20 acres located midway between the confluence of Barrel and Sand Creeks. This water was found to contain 31,600 mg/l chloride ion and 4,000 mg/l sulfate ion.

Another salt source exists at the confluence of Mitchell Creek. A small flow issuing from beneath a thin, warped selenite and gypsum bed had concentrations of 4,430 mg/l chloride ion and 2,800 mg/l sulfate ion.

Another source in this area is located at the confluence of Tule Creek. A salt encrustment exists for about one-half mile up the creek from the confluence and is generally restricted to the creekbed. Salt water seeps exist along the side of the creek during periods of flow. About three-quarters of a mile up Tule Creek from the confluence, the chloride ion concentration averages about 240 mg/l. This point is considered to be upstream from the upper limit of the salt source.

An unnamed creek, which enters the river from the north about 2½ miles upstream from the Bull Run Creek confluence is also considered a salt source. A heavy salt encrustment covers an area of about 20 acres at the confluence, forming a salt flat which is about 2 or 3 feet above the riverbed elevation. Although no flow was found coming from this creek, a sample from a pool had a concentration of 22,000 mg/l chloride ion and 4,200 mg/l sulfate ion.

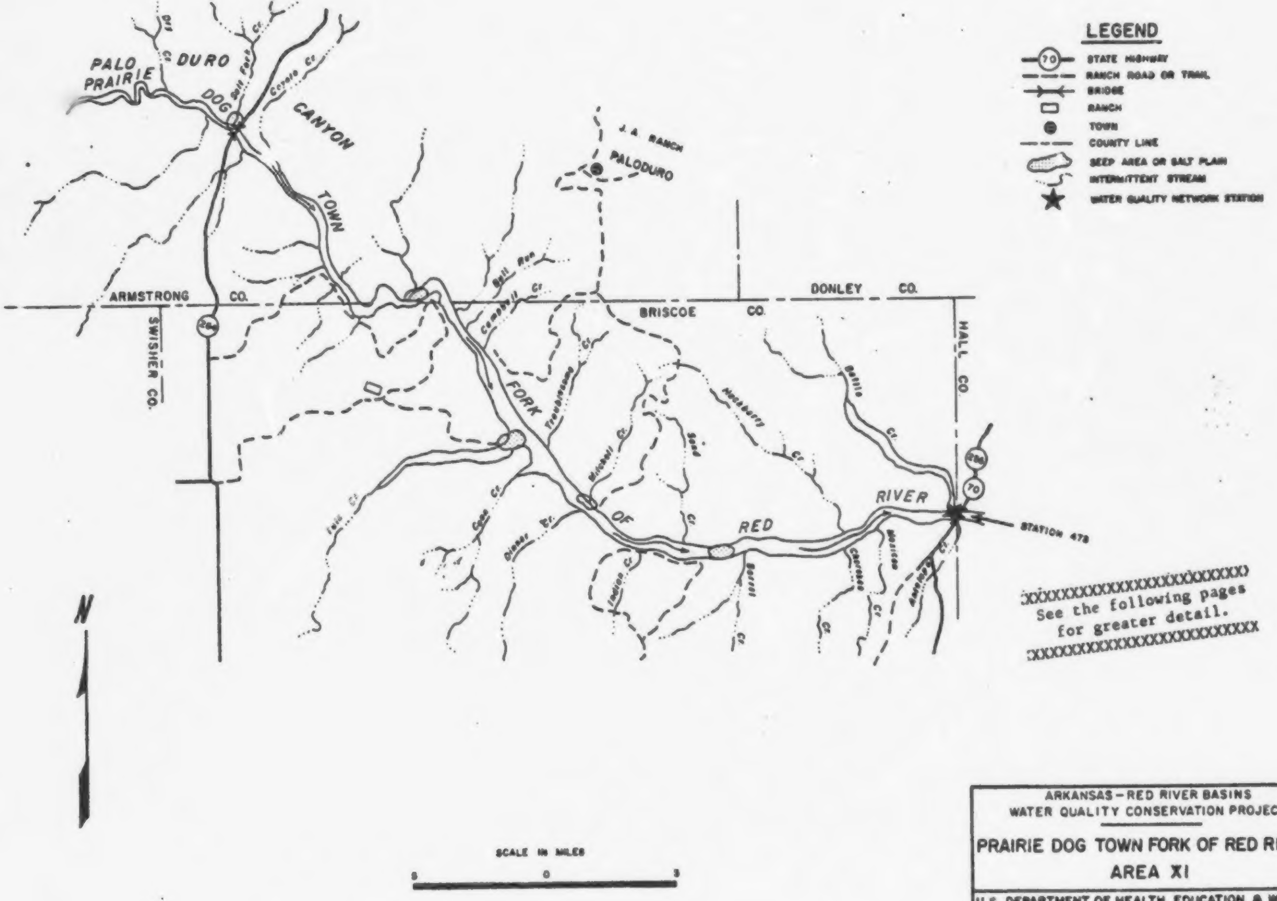
Another salt source is located at the confluence of Salt Fork Creek. Salt encrustment extends up the creek from its confluence for several hundred yards. Although flow is usually very low, the chloride concentrations average about 11,000 mg/l. There is a very heavy chloride ion pickup in the river flow from above to below the confluence of this stream. Analysis of water from this source is given on Table IV-15.

One well, drilled on the high plains of the J. A. Ranch to the north of this area, reportedly encountered bedded salt at about 600 feet. Relative elevations would place this salt zone at a relatively shallow depth beneath the river in this area.

Assuming that shallow salt beds exist below the river surface as reported, the river throughout this entire stretch should be considered as a potential salt source. The alluvially stored salt is dissolved and flushed downstream during periods of high flow.

Salt Load

The average chloride and sulfate releases from the area, as revealed by Station 478, are 175 and 30 tons per day, respectively.


LEGEND
70 STATE HIGHWAY
RANCH ROAD OR TRAIL
BRIDGE
RANCH
TOWN
COUNTY LINE
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
WATER QUALITY NETWORK STATION
PALO DURO CANYON
PRAIRIE DOG TOWN FORK OF RED RIVER
J. A. RANCH
PALODURO
ARMSTRONG CO.
SWISHER CO.
BRISCOE CO.
DONLEY CO.
HALL CO.
Coyote Cr.
Bull Run
Campbell Cr.
Mitchell Cr.
Sand Cr.
Mulberry Cr.
Battle Cr.
Tule Cr.
Indian Cr.
Cherokee Cr.
207
256
70
STATION 473
N
SCALE IN MILES
3
0
3

XXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXX

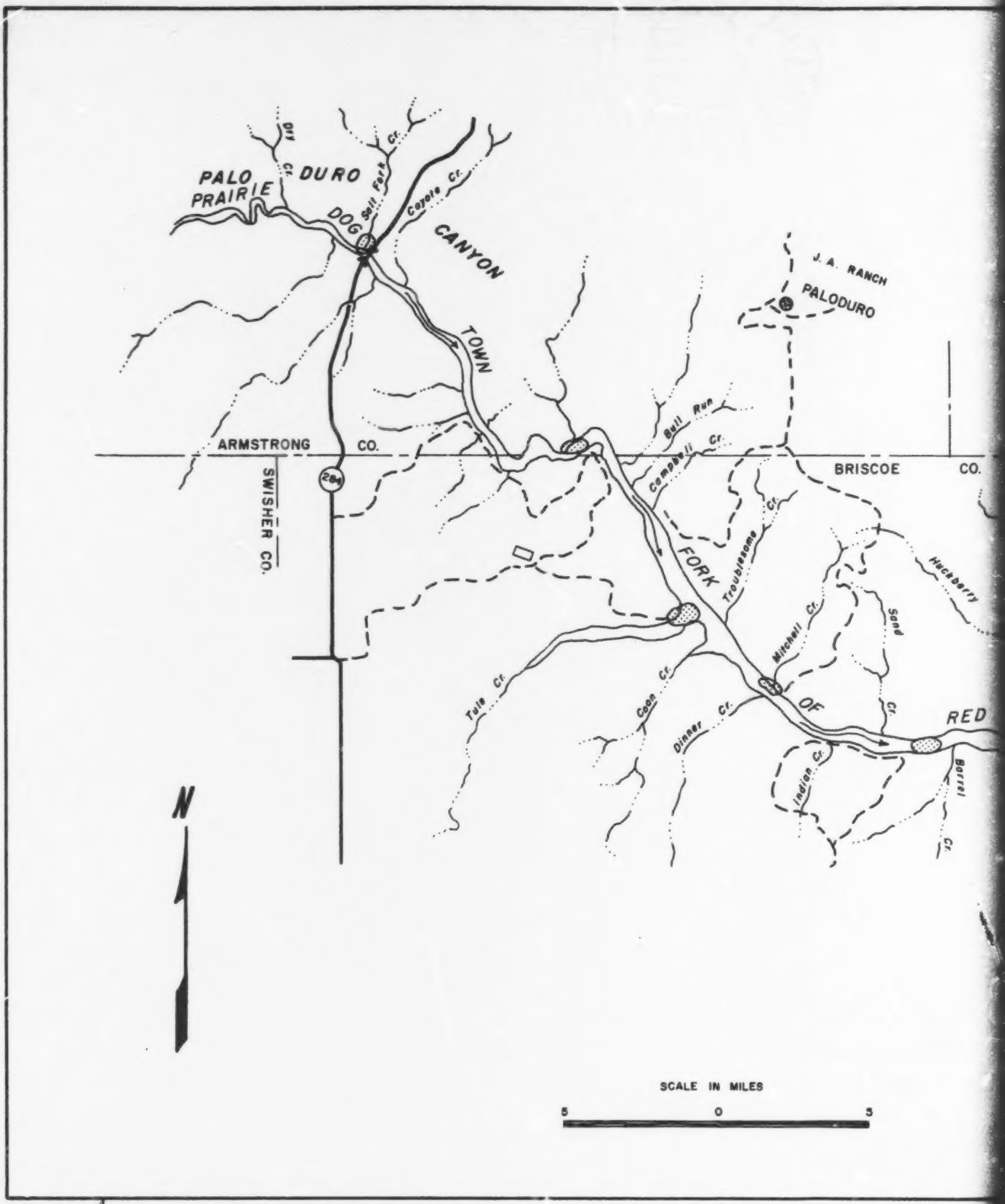
ARKANSAS – RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

PRAIRIE DOG TOWN FORK OF RED RIVER
AREA XI

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

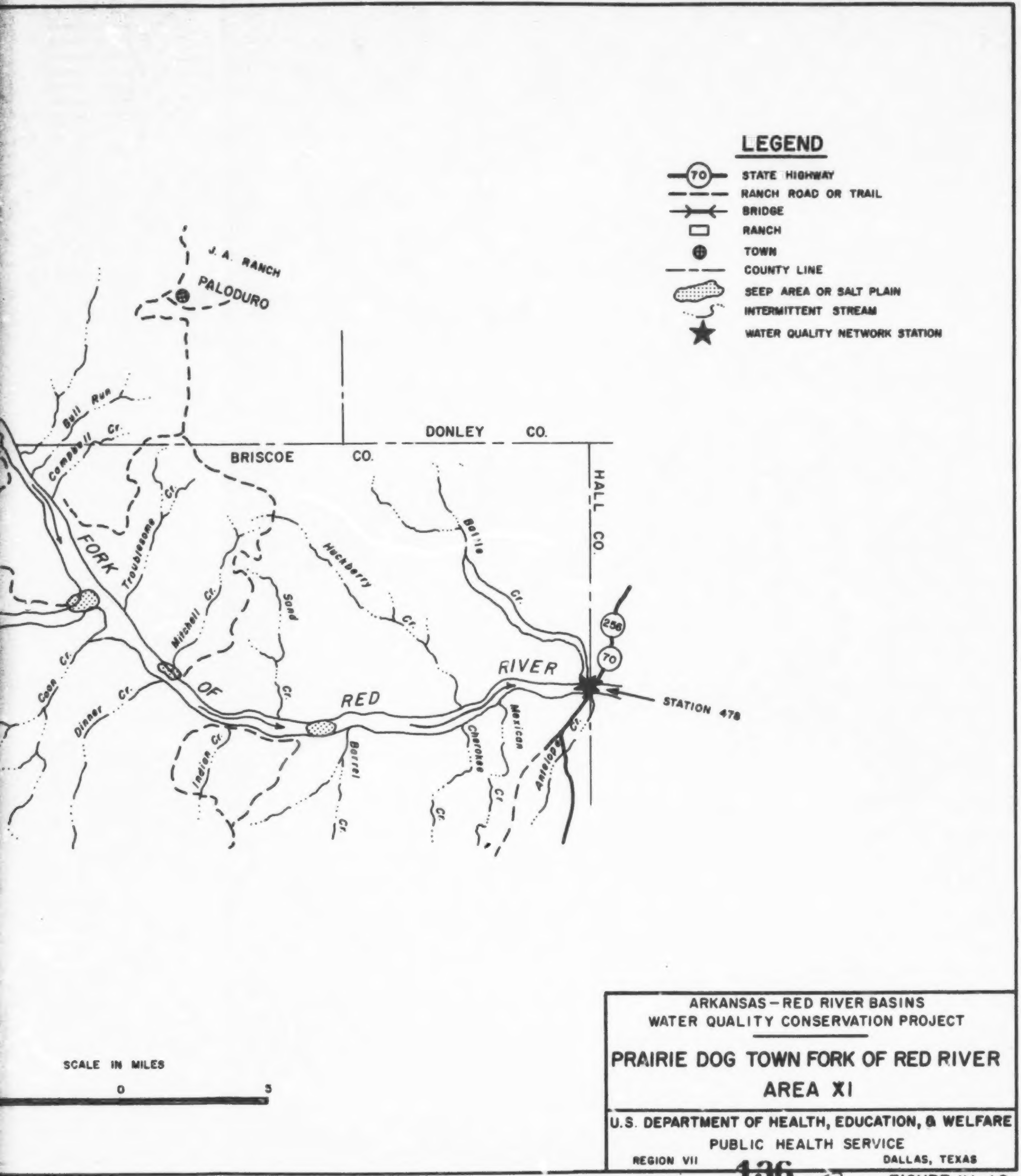
FIGURE IV-18

769 560 O 65 (Face p. IV-40)


PALO DURO
PRAIRIE DOG TOWN
CANYON
FORK
OF
RED
Dry Cr.
Sall Fork Cr.
Coyote Cr.
J. A. RANCH
PALODURO
Bull Run
Campbell Cr.
ARMSTRONG CO.
BRISCOE CO.
SWISHER CO.
284
Troublesome Cr.
Hackberry
Sand Cr.
Mitchell Cr.
Tule Cr.
Coon Cr.
Dinner Cr.
Indian Cr.
Barrel Cr.
N
SCALE IN MILES
5
0
5

769-160 O-63 (Face p. IV-40)

A


LEGEND
70 STATE HIGHWAY
RANCH ROAD OR TRAIL
BRIDGE
RANCH
TOWN
COUNTY LINE
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
WATER QUALITY NETWORK STATION
J. A. RANCH
PALODURO
DONLEY CO.
BRISCOE CO.
HALL CO.
Bell Run
Campbell Cr.
Troublesome Cr.
Mitchell Cr.
Sand Cr.
Huckberry Cr.
Bottle Cr.
FORK OF RED RIVER
Coon Cr.
Dinner Cr.
Indian Cr.
Barrel Cr.
Cherokee Cr.
Mexican Cr.
Antelope Cr.
256
70
STATION 478
SCALE IN MILES
0
3

ARKANSAS – RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

PRAIRIE DOG TOWN FORK OF RED RIVER
AREA XI

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-18

Table IV-15

Chemical Analysis of Natural Brines
Prairie Dog Town Fork Red River - Area XI

	Collection Point Salt Fork Creek
Date collected	9-6-62
pH	6.6
Spec. cond. 25°C, micromhos/cm	34,000
Total alkalinity ($CaCO_3$)	122
Total hardness ($CaCO_3$)	5,000
Dissolved solids	42,700
Calcium (Ca)	1,300
Magnesium (Mg)	400
Sodium (Na)	13,000
Potassium (K)	150
Sulfate (SO_4)	4,600
Chloride (Cl)	20,500
Silica (SiO_2)	7
Boron (B)	1.4
Fluoride (F)	10
Turbidity, Jackson units	25

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

Prairie Dog Town Fork of Red River Downstream from Area XI

The eastern limit of this area is the Farm to Market Road 657 bridge across the Prairie Dog Town Fork of Red River, 10 miles west and 10 miles south of Memphis, Texas. The western limit is the Texas State Highway 70 bridge across the same river, near the Hall-Briscoe County line. The area is in the western half of Hall County, Texas, and includes the river and its tributaries, between the approximate river mile 1,097 and 1,110 of Red River.

Description of the Area

The geology of this area is very similar to that of Area XV, located a few miles to the south. Bedrock along this reach is the Whitehorse Sandstone of Permian age. The south river bank is characterized by steep cliffs about 100 to 200 feet high. The surface topography immediately north of the river is almost entirely composed of low rolling sand dunes. Mulberry Creek, the major tributary, is located near the western limit of the area. Drilling logs indicate that salt is about 400 to 800 feet below the surface, with the more shallow salt to the west. The river is intermittent in this reach, being dry much of the year.

Brine Emission

Salt water seeps are located about one mile west of the Farm Road 657 bridge on the north side of the flood plain. The flow from these seeps averages about 0.5 cfs and has a chloride ion concentration of about 2,100 mg/l.

The major continuous contributor of chloride in this area is Polecat Creek, a tributary from the north about 4 miles upstream from the Farm Road 657 bridge. The flow from this creek is approximately 2 cfs having a chloride ion concentration of about 9,200 mg/l.

Other salt sources are located in the immediate vicinity of the Mulberry Creek confluence. A salt flat is located about one-half mile northwest of the confluence in a lowlying area. This salt flat covers about 7 acres and contributes to the river only during runoff periods. Other sources are a deep pool and a few seeps at the western confluence of the creek. The pool and seeps are connected by very small flows which are lost to the subsurface alluvium of the river. The chloride ion concentration of this water averages about 5,000 mg/l.

Salt Load

Average flow and concentration data indicate approximately 80 and 15 tons per day, respectively, of chloride and sulfate are contributed to the river in this area. The average flow and chloride and sulfate ion concentrations from gagings and grab sample analyses at Farm Road 657, when little or no flow occurs at State Highway 70 are about 2.6 cfs and 7,000 and 2,000 mg/l, respectively.

Lebos Creek

This salt source is located approximately 4 miles south of Eldorado, Jackson County, Oklahoma. The principal salt water pollution along the stream occurs from 3 to 5 miles above its confluence at river mile 1,019 of Red River.

Description of the Area

The topography in this area ranges from low, rolling hills to flat. The creek has cut through the red, gypsiferous Dog Creek Shale into the gypsum and gypsiferous shales of the Blaine draining to the southeast. Because ground water occurs at a higher elevation to the northwest, its movement is assumed to be in the same direction as that of the surface water.

Brine Emission

Ground water seepage occurs throughout the lower 10 to 12 miles of Lebos Creek, but the principal area of salt water seepage is in a 2-mile reach approximately 3 miles above the confluence.

Salt is reported 100 feet below the surface, a few miles upstream to the northwest in T1N, R24W. This salt is near the Dog Creek-Blaine contact and is thought to be the origin of the salt water in the seep area. A well, one mile west of the salt seep area, reportedly encountered salt water at a depth of 86 feet.

Two small tributaries contribute flow to the stream in this reach, but the increase in the Lebos Creek flow is attributed to seepage within the streambed. The two tributaries are the outlet flow channels of two small salt flats. These flats were not found to be of the magnitude reported in 1913 by Snider.

Salt Load

The average chloride and sulfate ion loads for this system are about 80 and 30 tons per day, respectively, excluding flush flows.

Elm Fork of Red River - Area VI

The area is located in the extreme northwestern corner of Harmon County, Oklahoma. Salt springs are located in three box canyons: Salton Canyon, Robinson Canyon, and Kiser Canyon. These canyons are along the south bank of the Elm Fork extending from approximately one mile west of Oklahoma State Highway 30 to 3 miles east of the Texas-Oklahoma State line (Figure IV-19).

Description of the Area

Bedrock in this area is of Permian age; and the exposed formations, in descending order, are the Dog Creek Shale, Blaine Gypsum, and Flowerpot Shale. Steep-walled canyons have been eroded about 200 feet below the surrounding upland through the Dog Creek, Blaine, and into the Flowerpot.

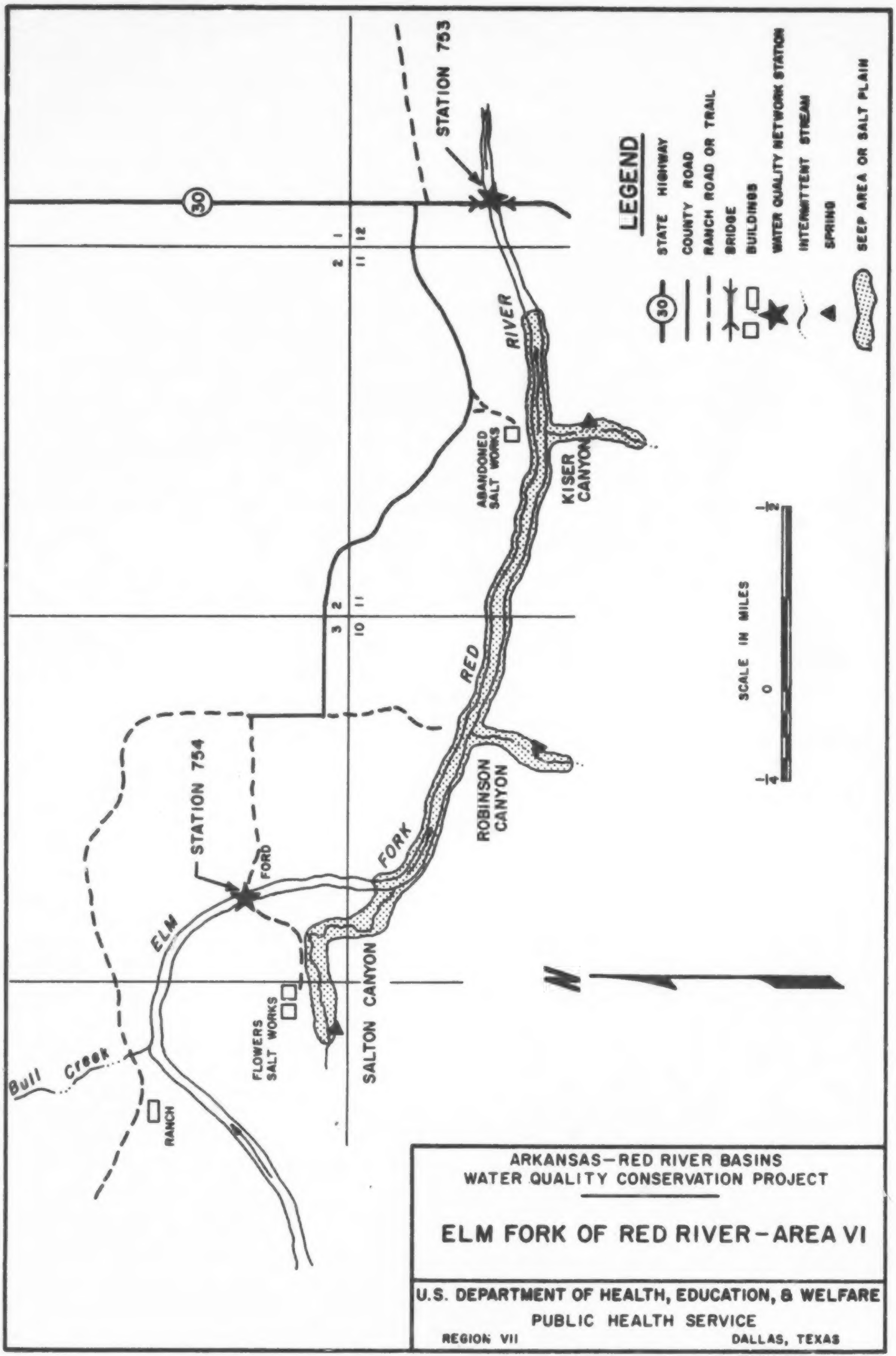
The regional dip for the Permian in southwestern Oklahoma is about 14 feet per mile to the south-southwest, however, this dip is sometimes altered by local structure, as is the case in this area.

Test hole data, as shown on Figure IV-20, indicate that a small structural ridge arches around the western side of Salton Canyon, and that salt-bearing shale in the Flowerpot is at a relatively higher elevation than the canyon.

The Blaine is the caprock in the immediate area. It is composed of massive gypsum beds separated by red, gypsiferous shale, and in some places, the gypsum is underlain by thin dolomite beds. The Blaine in this area is also characterized by sinkholes, solution channels, and small caves caused by the solvent action of ground water. The surface drainage area of the three canyons is about 18 square miles. Local terrain appears highly favorable for ground water recharge from precipitation.

Red and gray gypsiferous shale predominates in the Flowerpot Shale, which in this area, is greater than 220 feet thick. Halite, both disseminated in the shale and in lenticular beds, occurs commonly in the Flowerpot. Of nine test holes which were drilled in this area, salt water was found in all except one.

Although the permeability of the Flowerpot Shale is low, it is capable of collecting and transmitting small quantities of water through cracks and fractures, as evidenced by small springs in the formation at the base of cliffs. Numerous selenite veins up to 2 inches in thickness, offer further evidence of ground water movement within the shale.

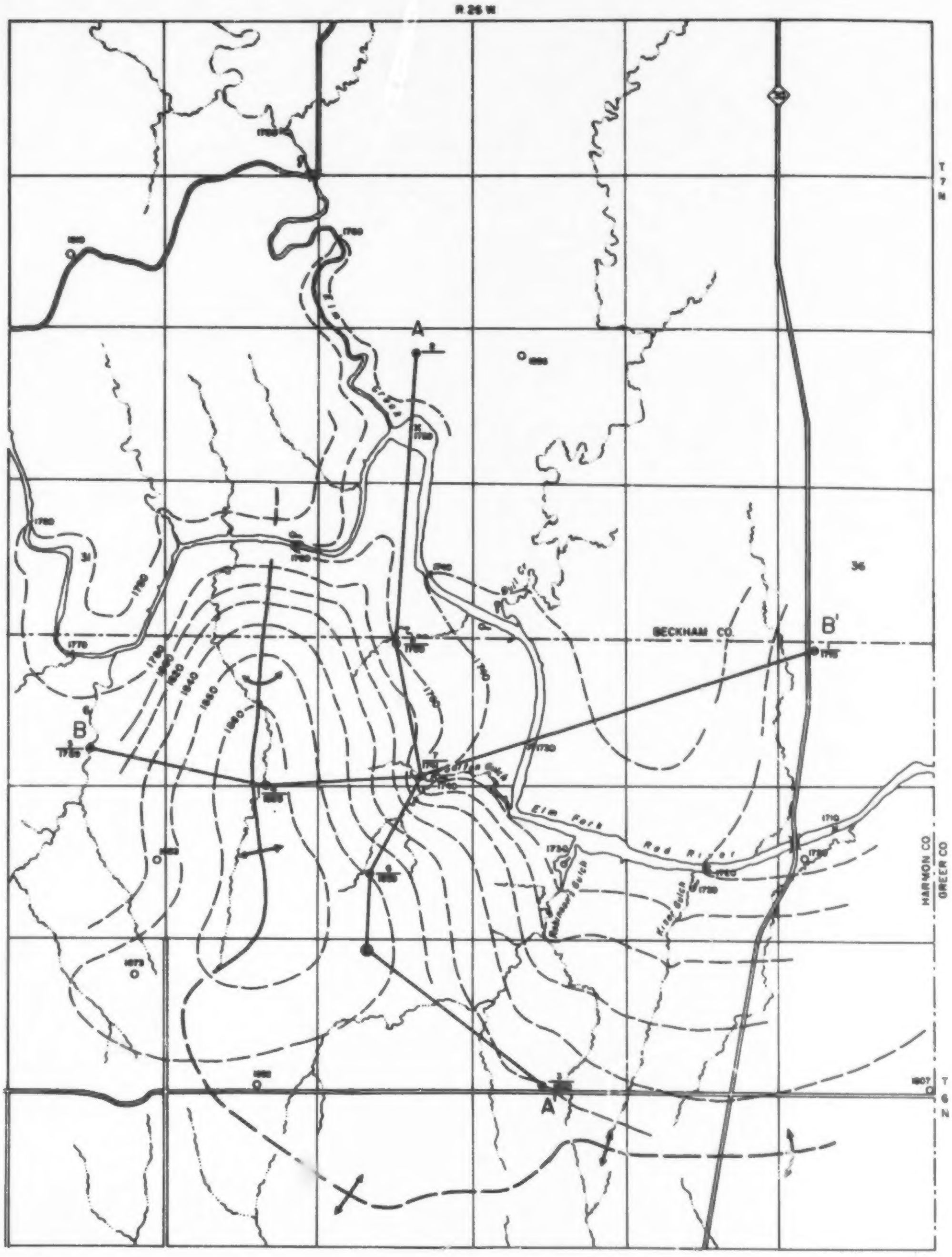

STATION 753
30
LEGEND
STATE HIGHWAY
COUNTY ROAD
RANCH ROAD OR TRAIL
BRIDGE
BUILDINGS
WATER QUALITY NETWORK STATION
INTERMITTENT STREAM
SPRING
SEEP AREA OR SALT PLAIN
RIVER
RED
FORK
ELM
ABANDONED SALT WORKS
KISER CANYON
ROBINSON CANYON
SALTON CANYON
FLOWERS SALT WORKS
STATION 754
FORD
Bull Creek
RANCH
SCALE IN MILES
0
N
2 1
11 12
3 2
10 11

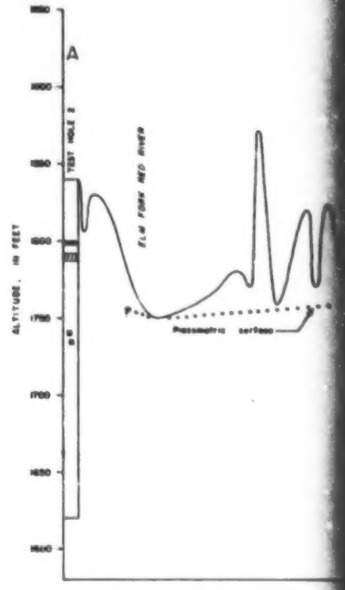
ARKANSAS–RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

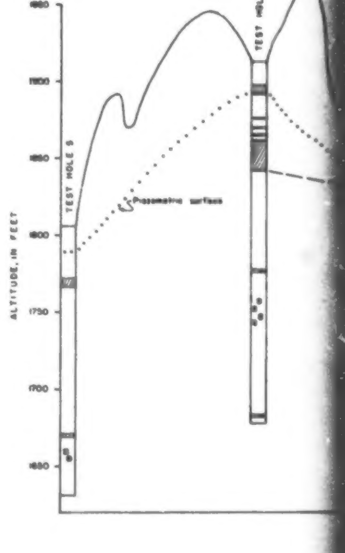
ELM FORK OF RED RIVER – AREA VI

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

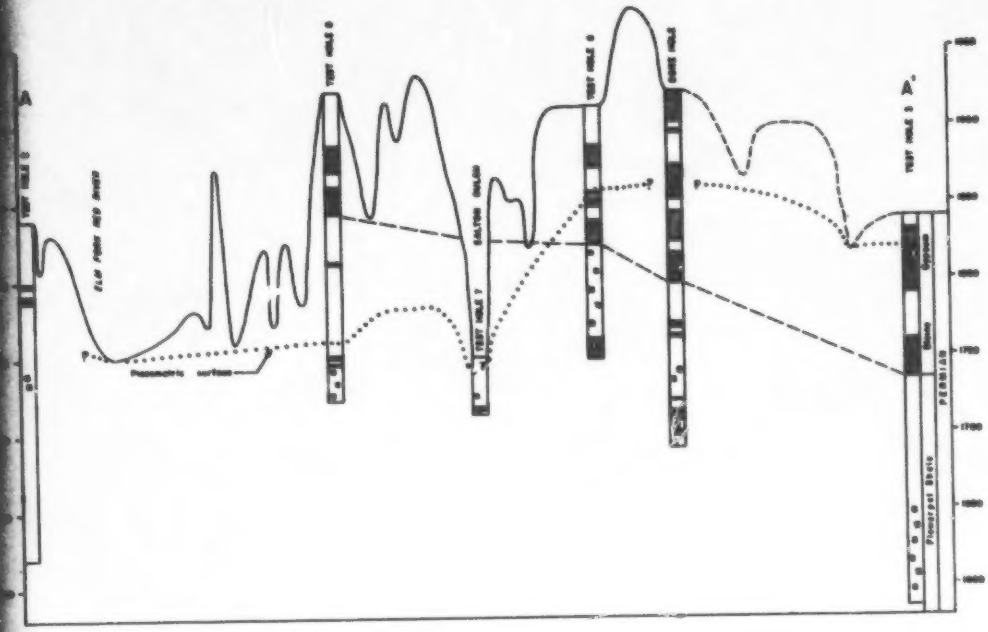
FIGURE IV-19

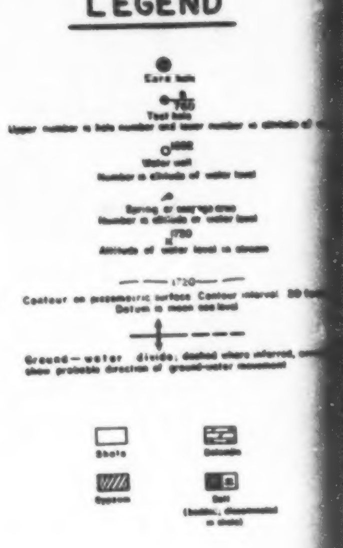

R 26 W
T 7 N
T 6 N
A
A'
B
B'
BECKHAM CO
HARMON CO
GREER CO
Elm Fork Red River
Robinsons Gulch
Kiser Gulch
Cotton Gulch
36
31
1760
1770
1780
1800
1820
1840
1860
1730
1720
1710
1807

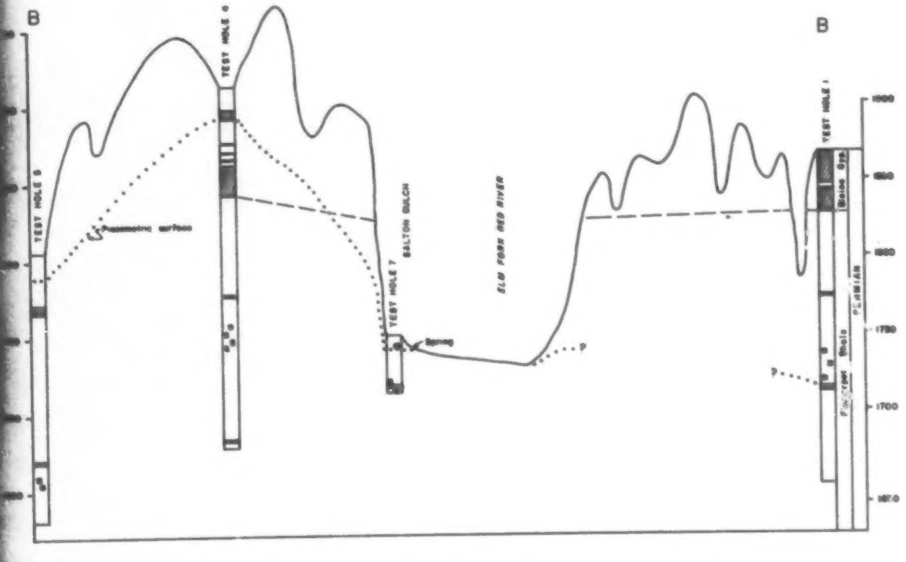

A
ALTITUDE, IN FEET
TEST HOLE 2
ELM FORK RED RIVER
Piezometric surface

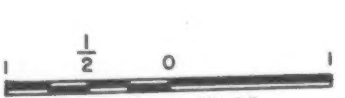

B
ALTITUDE, IN FEET
TEST HOLE 5
TEST HOLE 4
Piezometric surface
1800
1750
1700
1650

B


A
A'
ELM FORK RED RIVER
TEST HOLE
SALTON GULCH
TEST HOLE 7
CORE HOLE
Piezometric surface
?
Gypsum
Blaine
Flowerpot Shale
PERMIAN
1700


LEGEND
Core hole
Test hole
Water well
Number is altitude of water level
Spring or seepage area
Number is altitude of water level
1720
Altitude of water level in stream
1720
Contour on piezometric surface. Contour interval
Datum is mean sea level
Ground-water divide; dashed where inferred,
show probable direction of ground-water movement
Shale
Dolomite
Gypsum
Salt


B
B'
TEST HOLE
TEST HOLE 7
SALTON GULCH
ELM FORK RED RIVER
TEST HOLE 1
Piezometric surface
Spring
?
Blaine Gyp.
Flowerpot Shale
PERMIAN
1900
1850
1800
1750
1700

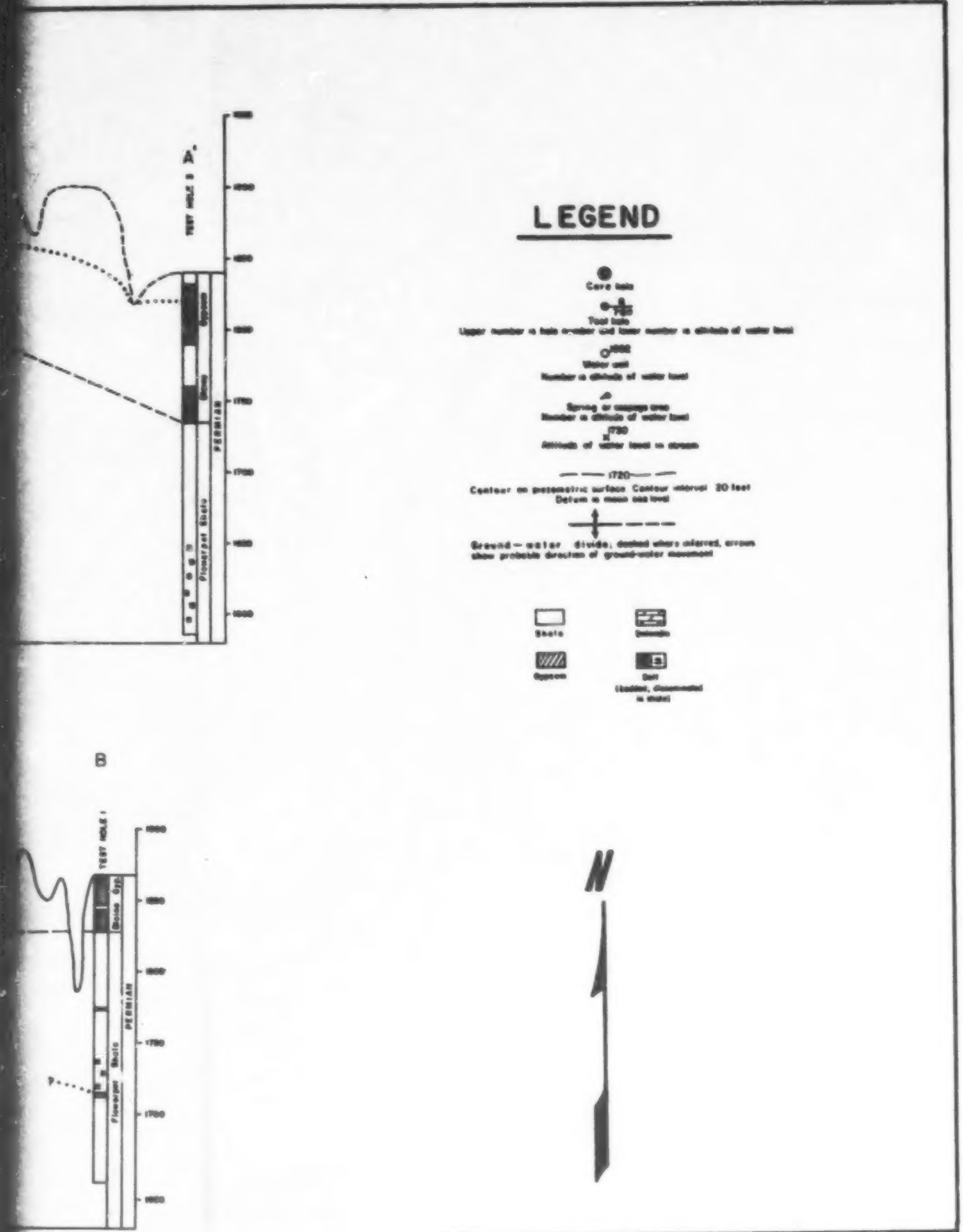

1
1/2
0
1
SCALE IN MILES

ARKANSAS–RED RI
WATER QUALITY CONSER

ELM FORK OF RED
PIEZOMETRIC SURFACE
MAP AND GEOLOG

U.S. DEPARTMENT OF HEALTH,
PUBLIC HEALTH
REGION VII

B


A'
TEST HOLE 8
Gypsum
Blaine
PERMIAN
Flowerpot Shale
LEGEND
Core hole
Test hole
Upper number is hole number and lower number is altitude of water level
Water well
Number is altitude of water level
Spring or seepage area
Number is altitude of water level
1730
Altitude of water level in stream
1720
Contour on piezometric surface. Contour interval 20 feet
Datum is mean sea level
Ground-water divide, dashed where inferred, arrows show probable direction of ground-water movement
Shale
Dolomite
Gypsum
Salt
(bedded, disseminated in shale)
B
TEST HOLE 1
Blaine Gyp.
PERMIAN
Flowerpot Shale
?
1700
N

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

ELM FORK OF RED RIVER-AREA VI
PIEZOMETRIC SURFACE-WELL LOCATION MAP AND GEOLOGIC SECTIONS

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-20

An exploratory boring about one mile southwest of Salton Canyon in Section 16, T6N, R26W, penetrated a 3-foot shale zone in the Flowerpot containing salt crystals and solution voids at a depth of 200 feet. At a depth of about 204 feet, the interbedding of halite and shale exhibiting empty and partially filled vugs suggests strongly that the salt is being removed through solution by ground water along the top of the salt-bearing beds. These beds are undoubtedly the source of the salt found in the springs in the canyons on the south side of the Elm Fork of Red River.

The main branch of the Elm Fork, South Elm Creek, contributes the majority of streamflow passing through Area VI. This stream contains water of good quality almost to its confluence with North Elm Creek. The waters of North Elm Creek are poor in quality throughout and contribute a chloride ion load of about 16 tons per day.

During normal flow periods, some salt storage takes place on the sandy alluvium of the stream. These storage plains do not have a heavy encrustment but are quite extensive for about 12 miles downstream from Station 754. This salt is flushed downstream by high flows.

Brine Emission

In Salton, Robinson, and Kiser Canyons, salt springs bubble up through the sand-covered canyon floors. A few springs issue from the Flowerpot Shale at the base of the canyon walls.

Salton Canyon produces about one-half of the combined chloride ion load from the three canyons. The Salton Salt Company operates a solar evaporation salt plant in this canyon, having a production area of about 400,000 square feet and a capacity of about 15,000 tons of salt per year. The water has a chloride ion content of 25 percent (190,000 mg/l) and yields about 3 pounds of salt per gallon. Average flow from this canyon is about 0.3 cfs, and the chloride contribution varies from 100 to 150 tons per day, depending on the amount of water being used by the salt company.

Robinson, the middle canyon, has an average flow of about 0.4 cfs, excluding flushing flows from rains. The chloride ion concentration of this water averages about 90,000 mg/l. Three individual salt springs are located in this canyon. Each have approximately the same flow and concentration, and produce a chloride ion load of 75 to 100 tons per day.

Kiser Canyon has an average flow of about 0.1 cfs and a chloride ion concentration of about 180,000 mg/l. There is an abandoned salt processing works in this canyon, and crystalline salt about one foot in thickness is present. Two specific springs are located in this canyon, and the average chloride ion loading is about 50 tons per day.

Between Station 754 at Salton Crossing, one-half mile above Salton Canyon, and Station 753, three-fourths mile downstream from Kiser Canyon, there is an increase in chloride ion load of about 250 tons per day. Most of this average daily load is contributed by the three canyons, with the remainder probably coming from subsurface salt water releases into the alluvial flow bed of the river.

Bloesch (1942) reported finding salt springs on the south bank of the river upstream from the canyons which could not be located during the investigation. However, the stream gaging and sampling in this reach did indicate a gradual increase in load in the 1½ mile reach above Station 754.

Analyses of waters from the area are given on Table IV-16.

Salt Load

The major salt load in this area comes from the three box canyons: Salton, Robinson, and Kiser. The total chloride loading from these canyons is approximately 250 tons per day. The sulfate contribution is about 10 tons per day. In addition to this load, a contribution of about 160 tons per day of chloride and 200 tons per day of sulfate originate on Elm Fork above the canyon area.

Elm Fork of Red River - Downstream from Area VI

This area is located on the Elm Fork of Red River to the east of Oklahoma State Highway 30 and Station 753.

Description of the Area

The bedrock in this reach is the Flowerpot Shale. Massive contamination of the waters by salt does not occur, but the remnant salt in the vicinity does cause minor pollution.

Brine Emission

Fish Creek, a tributary entering Elm Fork from the north about one mile downstream from Station 753, has water with an average chloride ion concentration of 5,000 mg/l. The average flow from this creek, excluding flush flows, is only about 0.2 cfs. The salt source is a small spring about 3 miles up from its confluence.

Table IV-16

Chemical Analyses of Natural Brines
Elm Fork of Red River - Area VI

	Collection Point		
	Kiser Canyon Flow Channel	Robinson Canyon Flow Channel	Salton Canyon Flow Channel
Date Collected	9-8-60	9-8-60	9-8-60
pH	7.2	7.2	7.1
Specific Gravity, 20°C	1.1935	1.1930	1.1897
Spec. cond. 25°C, micromhos/cm	185,000	190,000	190,000
Total alkalinity ($CaCO_3$)	40	44	24
Total hardness $CaCO_3$)	12,400	12,800	13,600
Dissolved Solids	315,000	308,900	304,000
Calcium (Ca)	1,600	1,840	1,840
Magnesium (Mg)	2,040	1,995	2,185
Sodium (Na)	118,800	116,300	112,500
Potassium (K)	380	340	340
Sulfate (SO_4)	3,200	3,300	3,000
Chloride (Cl)	180,000	185,000	184,000
Iron (Fe)	0.10	0.10	0.10
Boron (B)	5.2	4.2	2.5
Fluoride (F)	2.8	3.3	3.3
Bromine (Br)	200	86	92

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

A minor salt plain exists about 4 miles east of Station 753 and north of the river on an unnamed tributary. Some pooled water was observed at times, but no flow was evidenced.

An unnamed tributary, 5 miles north and 4½ miles east of Reed, Oklahoma, has a chloride ion concentration of 17,600 mg/l, with a flow of less than 0.1 cfs. The salt sources are small seeps about one mile above the confluence to the north of the Elm Fork.

Another unnamed creek, 2½ miles north and 2½ miles east of Reed, Oklahoma, has a flow of 0.2 cfs, with a 2,180 mg/l chloride ion concentration.

A salt source exists on Haystack Creek about 20 miles above its confluence, or 5 miles southwest of Delhi, Oklahoma. The source is seeps of small volume that have a chloride ion concentration of about 32,000 mg/l. Although very little of the salt gets into the river during normal flow periods, evaporation leaves the salt in storage in the upper reaches of the creek, and it is eventually flushed into the river during periods of high flow.

Salt Load

Sufficient measurements for determining chloride and sulfate ion loads have not been made, however, it is estimated that 100 tons per day of chlorides and sulfates are contributed by this reach of the Elm Fork of the Red River.

Boggy Creek Salt Plain - Beckham County, Oklahoma

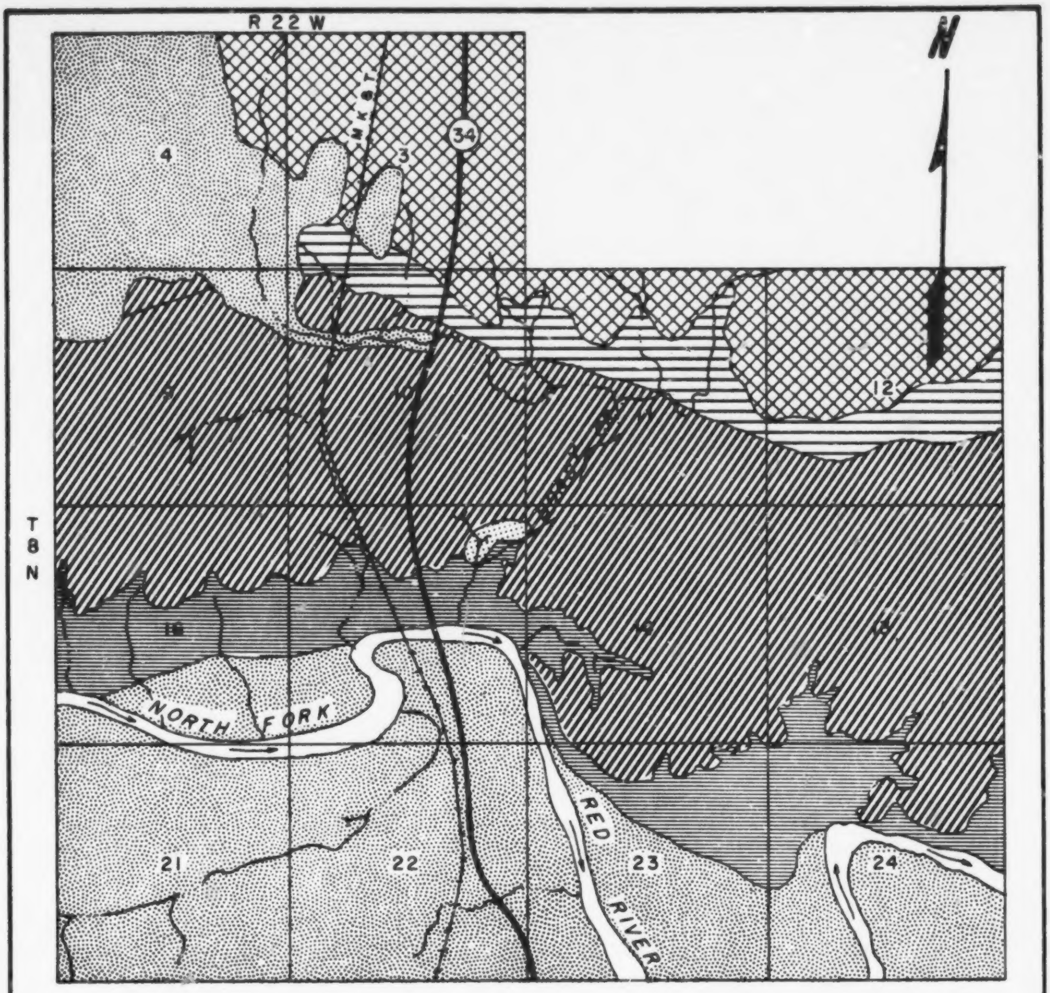
This area is located 2½ miles south and one-half mile east of Carter, Oklahoma, in the southeastern corner of Beckham County. The plain is on the northwest side of Boggy Creek, about one-half mile above its confluence with the North Fork of Red River at river mile 110 (Figure IV-21).

Description of the Area

The salt plain lies on the Flowerpot Shale Formation. Twenty-five foot cliffs of the Blaine Gypsum Formation border the north and west sides of the plain. The plain covers an area of about 40 acres and is separated from Boggy Creek by a ridge of alluvial sand except at the southwest end where flow from the plain enters the creek.

Brine Emission

Salt water issues from the base of the Blaine cliffs and from the surface of the plain. The source of the salt content of the water is presumably halite deposits in the Flowerpot Shale,


R 22 W
T 8 N
N
4
3
M K & T
34
12
16
NORTH FORK
RED RIVER
21
22
23
24
LEGEND
ALLUVIUM AND TERRACE DEPOSITS
QUATERNARY
WHITEHORSE GROUP
DOG CREEK SHALE
BLAINE GYPSUM
FLOWERPOT SHALE
EL RENO GROUP
PERMIAN
SEEP AREA OR SALT PLAIN
0
1/2
1
SCALE IN MILES

ARKANSAS—RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

GEOLGIC MAP OF BOGGY CREEK SALT PLAIN AND SEEP AREA

BECKHAM COUNTY, OKLAHOMA

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-21

as salty zones in this formation can be seen along the west side of Boggy Creek. The salt probably is dissolved by ground water and brought to the surface by the springs. Although the recharge area is unknown, it is assumed to be small since the drainage area of Boggy Creek is only about 10 square miles.

Shallow deposits of salt have been reported to the north, but bedded salt is not known to be closer to the surface than about 500 to 600 feet near the spring area. The ground water movement is probably from the north and west.

Although numerous springs exist on the plain, the total flow is very small. The flows from the springs meander over the plain and unite before entering Boggy Creek. The salt crust on the plain is generally thin, but increases to 3 or 4 inches near the salt springs. Some springs having a relatively good quality water are found at the extreme western edge of the plain. Boggy Creek, above the plain, has good quality water.

Salt Load

Because of the small amount of normal flow from the plain, the total chloride ion load entering the North Fork of Red River is small--only about 20 tons per day.

North and Middle Pease Rivers - Area IX

The area is located in the northeast quarter of Cottle County, Texas, on the North and Middle Pease Rivers. This is 18 and 13 miles, respectively, north of Paducah, Texas, and to the east of U.S. Highways 62-83. The lower limits of the areas appear to be about 2 miles upstream from the confluence of the two rivers which are located at river mile 75, about 3 miles west of the State Highway 104 bridge, across the Pease River. The upper source limit on the North Pease is just downstream from the U.S. Highways 62-83 bridge, and the upper source limit on the Middle Pease is about 1 mile downstream from the U.S. Highways 62-83 bridge on the Middle Pease (Figure IV-22).

Description of the Area

Both rivers have cut their valleys about 100 feet below the surrounding upland surface through the silty shale, gypsum, and dolomite of the Dog Creek Shale Formation, and possibly into the upper part of the Blaine Gypsum Formation. The valley floor is flat, covered with alluvial sand, and varies in width from a few hundred feet to approximately ½ mile. The uplands are predominately Dog Creek Shale, with some Whitehorse Sandstone cropping out to the west.

The surrounding uplands appear favorable for ground water recharge. Exposed gypsum contains solution openings and fractures, making it capable of absorbing and transmitting appreciable quantities of ground water. Depth of bedded salt in this area ranges between 300 and 1,100 feet. Salt may also exist at more shallow depths as stringers in the Blaine and Dog Creek.

Brine Emission

Most of the salt water appears at the surface as seeps rather than springs. Flow measurements indicate water seeps into the streamflow channels of both the Middle and North Pease Rivers.

During normal flow periods, there is no surface flow at the confluence of the North Pease. Water samples collected from different points on the North Pease varied in concentration from 6,000 to 11,000 mg/l chloride ion.

The major salt source area on the Middle Pease occurs between the confluence of unnamed Creek No. 1 and a point about 1 mile east of the U.S. Highways 62-83 bridge. Unnamed Creek No. 1 and unnamed Creek No. 2 contribute a small amount of salt water to the river, as do numerous seeps. Flow in the tributaries originates from seeps and small springs in box canyons a short distance from the river. A seepage area in an apparent slump basin on the north side of the Middle Pease has standing water of 55,000 mg/l chloride ion concentration.

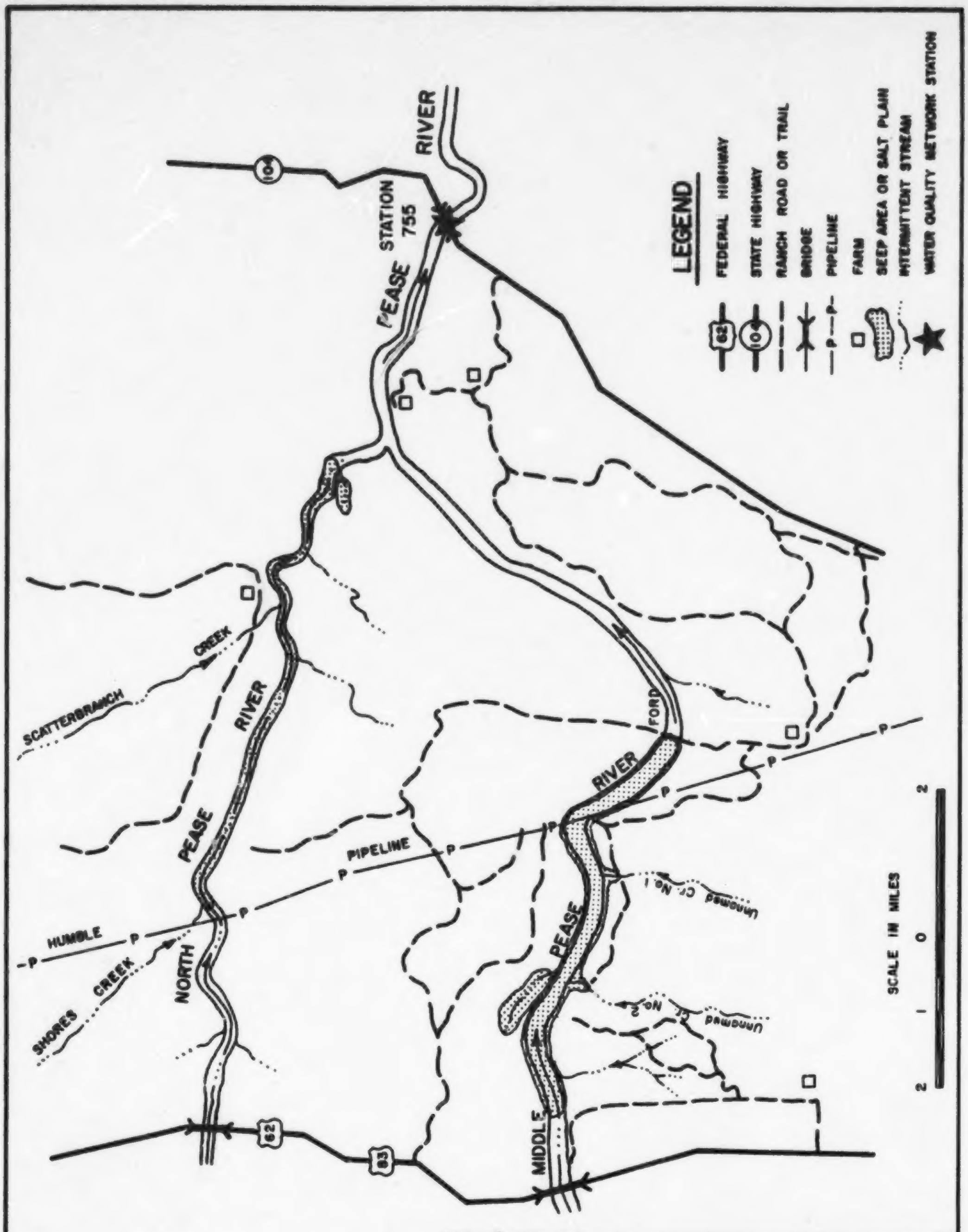
Between unnamed Creek No. 1 and the Middle Pease confluence with the North Pease, the flow decreases, while the chloride ion concentration remains relatively stable. In this same reach, there is a large alluvial storage potential, and the streambed between these two points has a continuous salt encrustment during dry weather. Upstream from U.S. Highways 62-83 bridge crossing, there are thin, spotty salt encrustments on both rivers.

Salt Load

A highly variable load of chloride and sulfate is derived from this area because of the intermittent precipitation pattern and the storage potential of the riverbeds and alluvium. An average for this area, as indicated by Station 755, is about 350 tons per day chloride and 20 tons per day sulfate.

North Wichita River - Area VII

The area lies about 8 miles southeast of Paducah in the southeast quarter of Cottle County, Texas. This includes Salt Creek


PEASE RIVER
STATION 755
104
LEGEND
FEDERAL HIGHWAY
STATE HIGHWAY
RANCH ROAD OR TRAIL
BRIDGE
PIPELINE
FARM
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
WATER QUALITY NETWORK STATION
SCATTERBRANCH CREEK
NORTH PEASE RIVER
FORD
RIVER
HUMBLE PIPELINE
SHORES CREEK
Unnamed Cr. No. 1
Unnamed Cr. No. 2
MIDDLE PEASE
62
83
SCALE IN MILES
2 1 0 2

ARKANSAS – RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

NORTH AND MIDDLE PEASE RIVERS
AREA IX

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-22

and the North Wichita River for about 3 miles downstream and 1 mile upstream from Salt Creek. Salt springs and seeps occur within these limits with the greater number being along the banks of Salt Creek (Figure IV-23).

Description of the Area

The surface rocks throughout the area exhibit a very complicated slump structure indicating that underlying materials, probably salt and gypsum, have been removed through solution. The springs emerge from cracks and holes in slumped and broken gray dolomites that are interbedded with the shales of the Dog Creek-Blaine interval. The dolomite beds average about 13 feet in thickness and at places are several feet above the water level of the creek. At other locations, they plunge beneath the creek, only to reappear a short distance away.

A boring drilled 1½ miles southwest of Spring No. 1 found the dolomite bed at a depth of 172 feet, which is about 70 feet lower than at the spring. This is a local westward dip of about 50 feet per mile and probably indicates slumping or local structure rather than regional dip. Shale beneath the dolomite was slumped as it would be if it had contained salt which had been removed by solution.

The uplands to the southwest of the spring area are covered with about 30 feet or more of unconsolidated sand and silt. The precipitation falling on these deposits is readily absorbed and retained long enough to allow some water to enter the underlying fractured shale, dolomite, and gypsum.

Salt storage along the North Wichita River, and especially Salt Creek, is quite evident during dry seasons. The storage along the streams is within the cut banks and is deposited within and on the alluvial sands of the streams. The greater storage is along Salt Creek even though alluvial sand quantity is small.

Brine Emission

The North Wichita River contributes only about 10 percent of the area chloride pollution from the reach above the Salt Creek confluence. One significant seep is located on the North Wichita River about 100 yards upstream from the Salt Creek confluence. The concentration of chlorides in this seep averages about 16,000 mg/l.

Springs and seeps on Salt Creek are the major contributors of brine in this area. Salt Creek at its confluence averages about 3.5 cfs during normal flow periods, and the chloride ion concentration averages about 17,000 mg/l.

Three distinct springs appear on Salt Creek. Spring No. 1, located on the south side about three-fourths of a mile above the confluence, has an average flow of approximately 0.6 cfs, with a chloride ion concentration of 17,000 mg/l. Spring No. 2, located on the north side about 2½ miles above the confluence, has an average flow of 0.3 cfs with a chloride ion concentration of 19,500 mg/l. Spring No. 3 is located about a mile upstream from Spring No. 2. This spring has a very small flow with an average chloride ion concentration of about 4,700 mg/l. The flow from the seeps and springs emit from thin-bedded, blocky, slumped, gray dolomite beds. Flow from the springs appears to vary seasonally. In August 1960, the flow of Spring No. 1 was 0.3 cfs as compared to 0.7 cfs in April 1961. The concentration of the water appears to be relatively stable at about 17,000 mg/l of chloride ion.

There is an improvement in the quality of water from springs and seeps of the North Wichita River downstream from the confluence of Salt Creek. The flow from these seeps and springs is small, usually less than 0.1 cfs. Approximately 3 miles downstream from the confluence of Salt Creek, an unnamed tributary from the south has a spring-fed flow of 0.3 cfs with an average concentration of about 3,500 mg/l chloride ion. South Cottonwood Creek has an average flow of about 0.3 cfs, and a chloride ion concentration of 1,400 mg/l.

A large spring located about 3 miles downstream from the county road iron bridge, Station 771, has characteristics which are similar to Spring No. 1 on Salt Creek, however, the chloride ion concentration is only 120 mg/l, and the flow about 1 cfs.

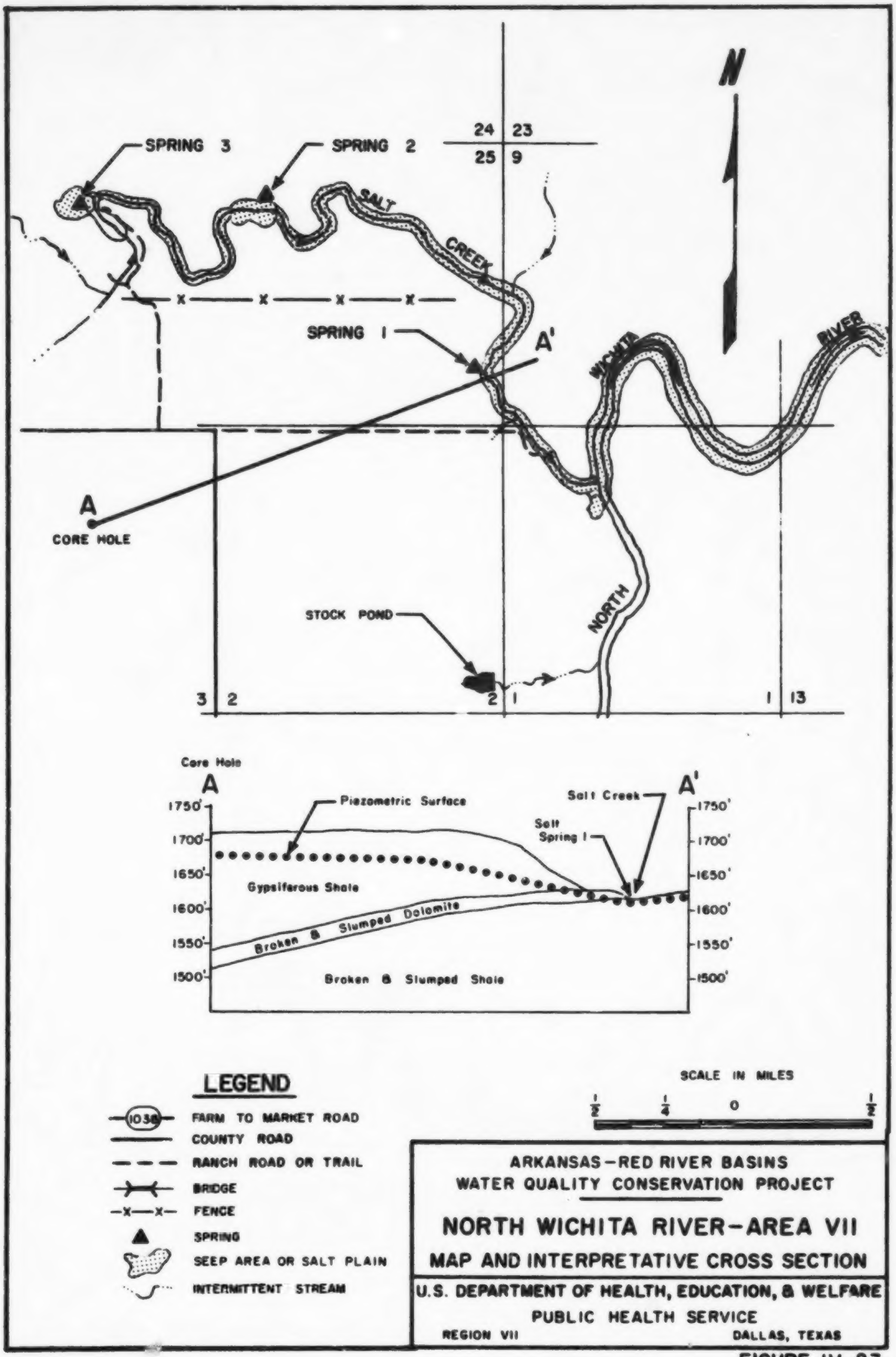
Analyses of waters from the area are given on Table IV-17.

Salt Load

Salt loads from this area are indicated by the records for Station 771. They show that an influx of about 200 tons per day of chloride and 20 tons per day of sulfate occur in this stretch.

South Fork of Wichita River - Area VIII

The area is located 4 to 6 miles east of Guthrie near the center of King County, Texas in the Bateman Estate Oilfield, and about 4 miles north of U.S. Highway 82. The lower limit of the salt spring and seep area is just below the Humble lease bridge crossing, about 1 mile north of the Humble Oil Company Production Camp. The upper limit of the area is approximately 4 river miles upstream from the bridge (Figure IV-24).

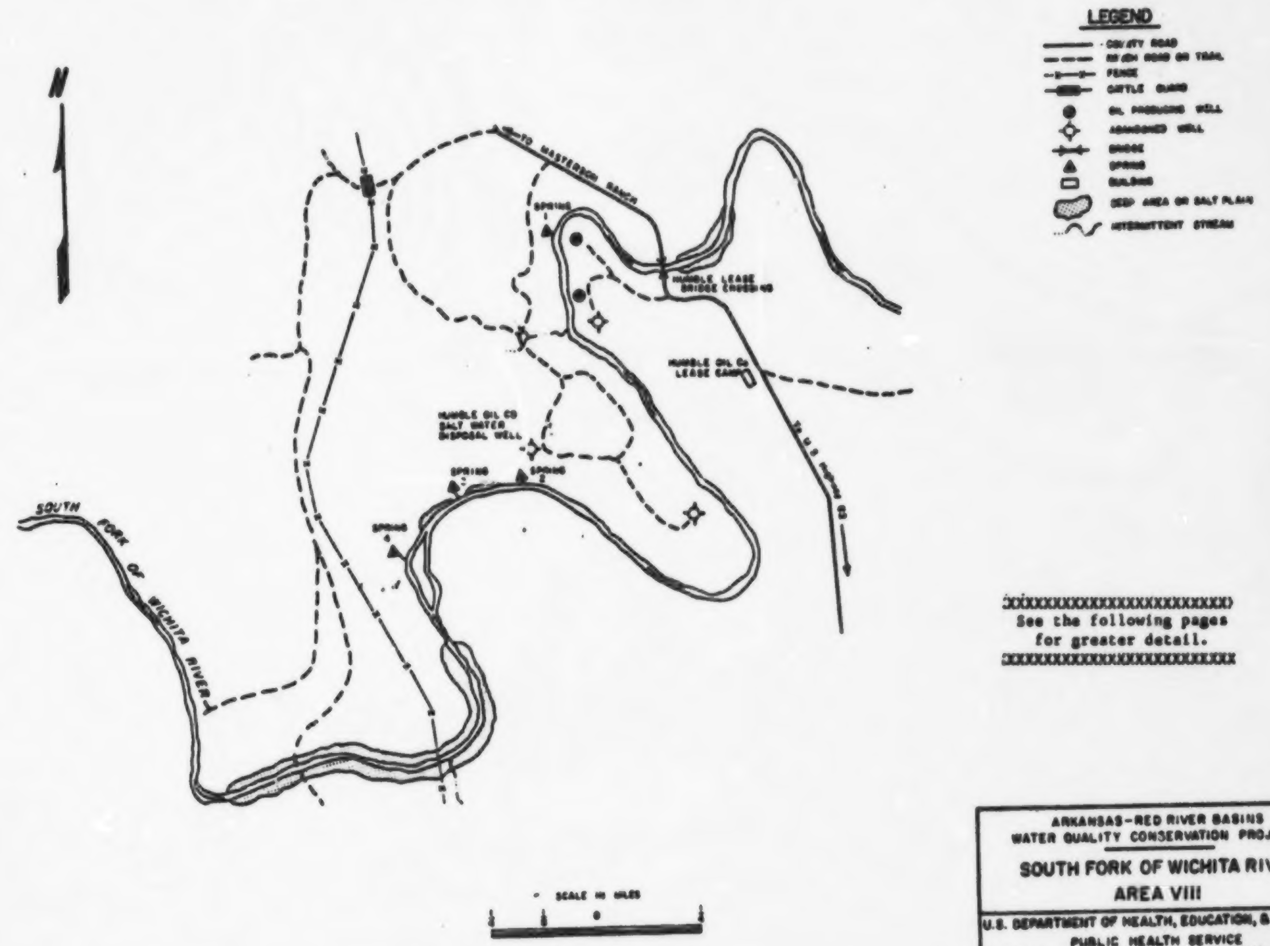

N
24 23
25 9
SPRING 3
SPRING 2
SALT CREEK
SPRING 1
A'
WICHITA RIVER
A
CORE HOLE
NORTH
STOCK POND
3 2
2 1
1 13
Core Hole
A
A'
Piezometric Surface
Salt Creek
Salt Spring 1
1750'
1700'
1650'
1600'
1550'
1500'
Gypsiferous Shale
Broken & Slumped Dolomite
Broken & Slumped Shale
LEGEND
1038 FARM TO MARKET ROAD
COUNTY ROAD
RANCH ROAD OR TRAIL
BRIDGE
FENCE
SPRING
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
SCALE IN MILES
1/2
1/4
0
1/2

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

NORTH WICHITA RIVER-AREA VII
MAP AND INTERPRETATIVE CROSS SECTION

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-23


LEGEND
COUNTY ROAD
RANCH ROAD OR TRAIL
FENCE
CATTLE GUARD
OIL PRODUCING WELL
ABANDONED WELL
BRIDGE
SPRING
BUILDING
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
N
TO MASTERSON RANCH
SPRING 1
HUMBLE LEASE BRIDGE CROSSING
HUMBLE OIL Co LEASE CAMP
HUMBLE OIL CO SALT WATER DISPOSAL WELL
SPRING 2
SPRING 3
SPRING 4
To U S Highway 82
SOUTH FORK OF WICHITA RIVER
SCALE IN MILES
1 0 1

XXXXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXXXX

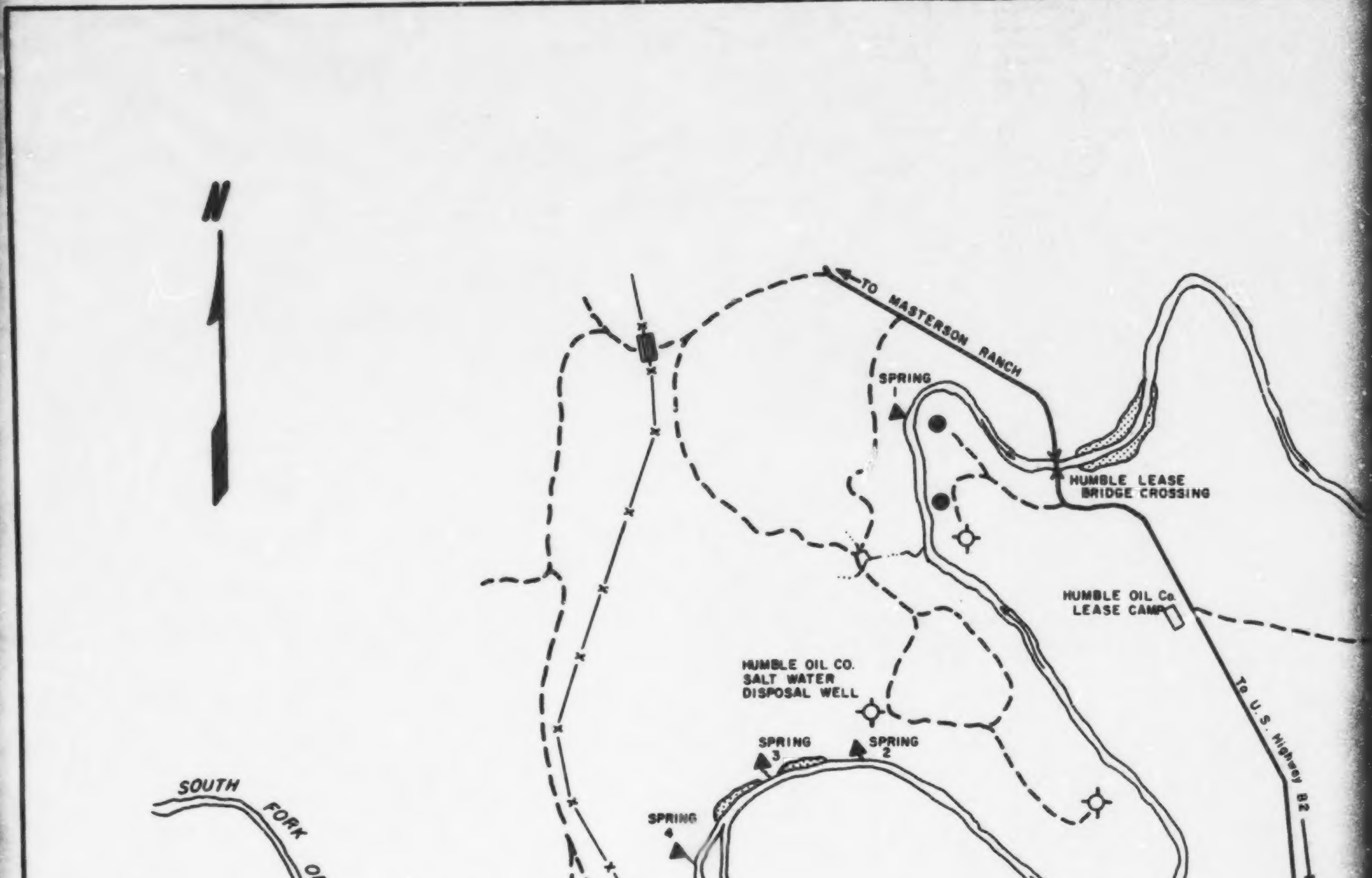
ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

SOUTH FORK OF WICHITA RIVER
AREA VIII

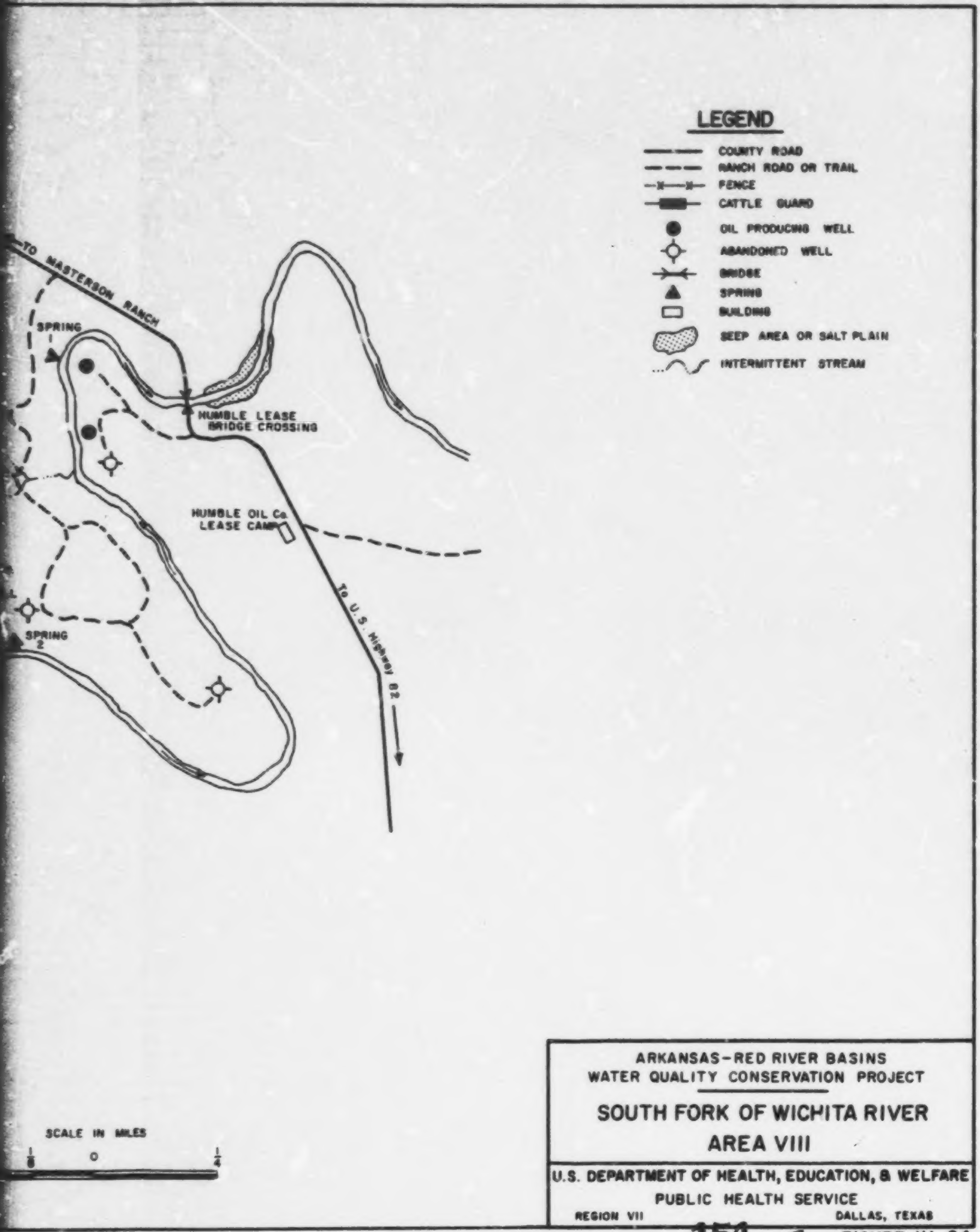
U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-24

769-568 O-65 (Face verso of fig. IV-23)


N
TO MASTERSON RANCH
SPRING 1
HUMBLE LEASE BRIDGE CROSSING
HUMBLE OIL Co. LEASE CAMP
HUMBLE OIL CO. SALT WATER DISPOSAL WELL
SPRING 3
SPRING 2
SPRING 4
To U.S. Highway 82
SOUTH FORK OF WICHITA RIVER
SCALE IN MILES
1/4 1/8 0 1/4

A


LEGEND
COUNTY ROAD
RANCH ROAD OR TRAIL
FENCE
CATTLE GUARD
OIL PRODUCING WELL
ABANDONED WELL
BRIDGE
SPRING
BUILDING
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
TO MASTERSON RANCH
SPRING 1
HUMBLE LEASE BRIDGE CROSSING
HUMBLE OIL Co. LEASE CAMP
To U.S. Highway 82
SPRING 2
SCALE IN MILES
1/8
0
1/4

ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

SOUTH FORK OF WICHITA RIVER
AREA VIII

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-24

B

Table IV-17

Chemical Analyses of Natural Brines
Salt Creek of North Wichita River - Area VII

	Collection Point		
	Salt Plain South of Spring No. 1 on Salt Creek	Spring No. 1 on Salt Creek	Stream Sample 300 Ft. Above Spring No. 1
Date Collected	9-14-60	9-14-60	9-14-60
pH	7.8	7.9	7.8
Specific Gravity 20°C	1.0208	1.0215	1.0169
Spec. cond. 25°C, micromhos/cm	40,000	41,000	39,000
Total alkalinity ($CaCO_3$)	138	104	48
Total hardness ($CaCO_3$)	6,000	5,200	5,600
Dissolved Solids	34,900	32,300	32,800
Calcium (Ca)	1,440	1,280	1,280
Magnesium (Mg)	585	485	585
Sodium (Na)	11,900	11,600	10,500
Potassium (K)	50	100	60
Sulfate (SO_4)	3,500	3,600	3,300
Chloride (Cl)	16,200	17,400	17,000
Iron (Fe)	0	0	0
Boron (B)	3.9	3.4	2.8
Fluoride (F)	1.8	0.9	1.4
Bromine (Br)	60	100	40
Manganese (Mn)	0	0	0

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

Description of the Area

The spring and seep area occurs where the Dog Creek Shale and Blaine Gypsum interval of Permian age crop out. In this area, the contact between these two formations is very hard to distinguish, and they are commonly referred to as the Dog Creek-Blaine Formation, or just the Blaine Formation. These two formations consist of massive gypsum beds, red and gray gypsiferous shales, and dense, fractured, impure dolomites. Dolomites in the upper Dog Creek contain many salt casts filled with a clay-like foreign substance.

The regional dip in this area is to the southwest, with some local alteration. The salt springs emerge at the base of steep cliffs near the edge and on the north side of the river. Seeps occur on both sides of the river.

The land surface of the area is predominately shale, but in many places weathered and broken dolomite and gypsum crop out. The dolomite and gypsum have the capacity to absorb appreciable amounts of precipitation, which makes the area quite favorable as a recharge area for the springs. Sinkholes in the area are another source of recharge. Most shales which are near the surface in this area are in a relatively pervious state due to disturbances.

A boring drilled to a depth of 289.6 feet about 1½ miles west-southwest of Spring No. 4 evidenced salt in a dolomite section between the depths of 246.3 feet and 248.5 feet. Examination of many oil well logs yielded very little information pertaining to the first few hundred feet of subsurface penetration. The Humble Oil Company maintains a subsurface injection well for the disposal of salt water produced within the Bateman Oilfield with the injection zone in the basal Canyon Sand, about 4,500 feet below the surface. Investigation of this area indicates little or no pollution from the Bateman Oilfield in the area above the bridge crossing.

During dry weather, salt encrustation forms on the alluvial sands of the river. Total salt storage is small since the alluvial deposits along this stream are not extensive. The stored salt is dissolved during rainy periods and carried downstream where the river flows into the North Wichita before entering Lake Kemp west of Wichita Falls, Texas. Thin salt and calcium sulfate encrustations have been observed along the river to the west of Guthrie, Texas, during dry periods, but no specific salt source has been identified.

The land surface slope suggests that the water movement toward the spring area is primarily from the north and west. The springs, being on the north side of the river and flowing at a higher elevation than the river, also support this conclusion. The salt pollution in the springs and seeps most likely originates from shallow salt inclusions in the Dog Creek-Blaine that is taken into solution by migrating ground water.

Brine Emission

The South Fork of Wichita River becomes a perennial stream at a point about 4 miles upstream from the Humble lease bridge crossing. This is where the first significant salt water seeps appear. A small spring has been found about 200 yards below the Humble lease bridge crossing in an area of general seepage. This spring has water of about 3,500 mg/l chloride, but the limited flow makes it accountable for only about 3 tons per day of chloride. Flow and quality data at Station 756, near Benjamin, Texas, the lower ford crossing 6 miles below the Humble lease bridge crossing, and the Humble lease bridge crossing support visual investigative information, indicating that for all practical purposes the lower limit of this area is at the latter.

For 4 miles upstream from the bridge, salt springs and seeps occur. Four significant springs are located in this area, but only one, Spring No. 4, has a higher chloride ion concentration than the river. This spring averages approximately 1.3 cfs in flow and contributes about 95 tons per day of chloride ions to the river, or approximately 50 percent of the chlorides from this area. For approximately 1½ miles above Spring No. 4, numerous seeps contribute a total of about 35 tons per day of chloride ions. Between the bridge crossing and Spring No. 4, there is an unaccounted for flow of approximately 1.5 cfs and a chloride ion load of about 35 tons per day.

Spring Nos. 1, 3, and 4 occur on the north side of the river and emerge from cavernous openings in the gypsum cliffs. The water level of the springs, as the flow emerges from the openings, is only a few feet above the water level of the river. Spring No. 2 emerges through cracks and holes in the top of a flat gypsum bed, which is about 3 feet above the water surface of the river.

Analyses of waters from the area are given on Table IV-18.

Salt Load

This area is monitored by Station 756, which is several miles downstream near Benjamin. Averages for this station are 200 and 20 tons per day of chloride and sulfate, respectively. The large majority of these loads originate from within the defined limits of the area, the remainder coming from above and below the limits.

Middle Fork of Wichita River - Area X

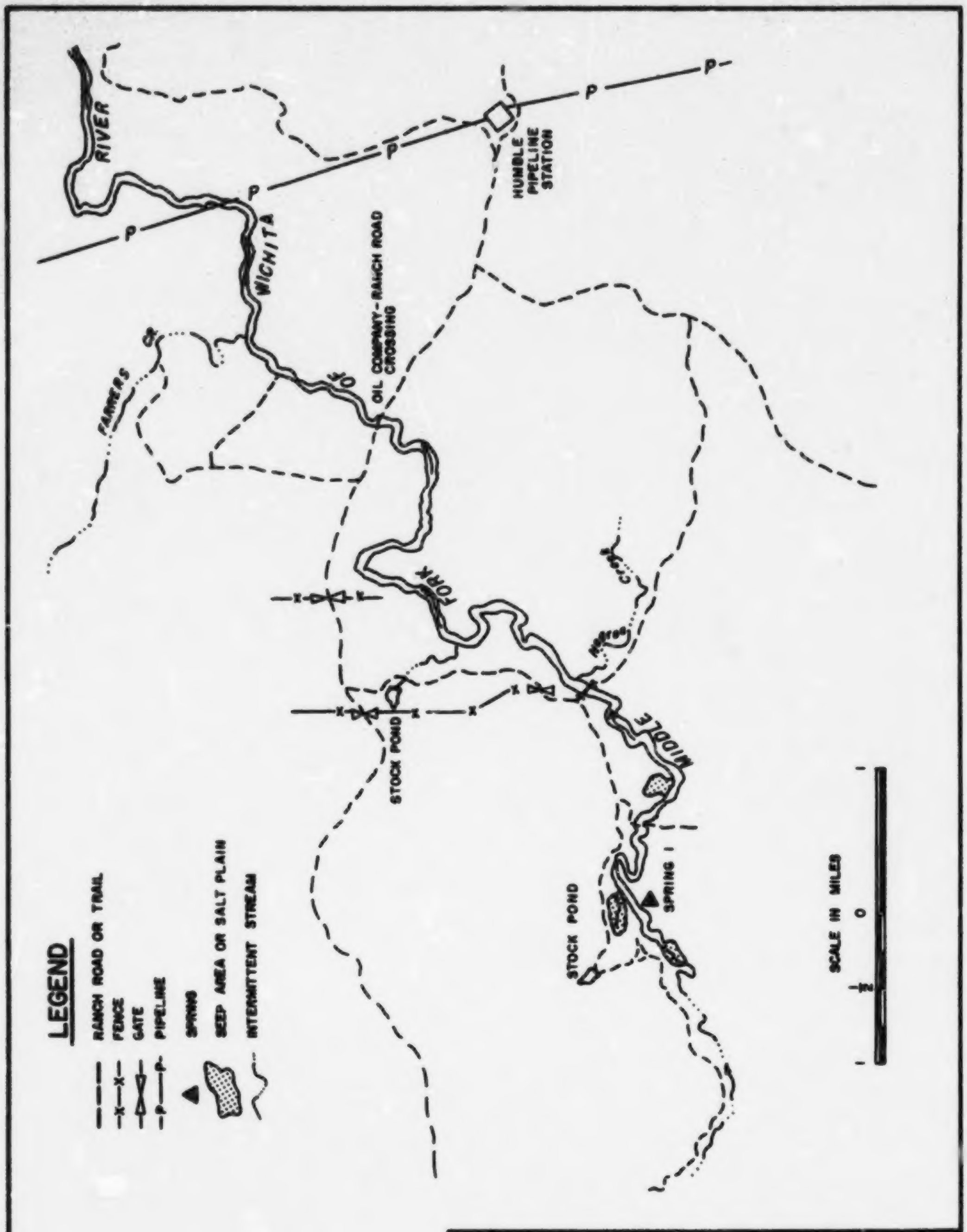
This area is located about 13 miles northeast of Guthrie, King County, Texas, on the Tom Masterson JY Ranch. This is about 15 miles above its confluence with the North Wichita River. The salt spring and seep area extends west from the oil company-ranch road bridge for a distance of about 6 river miles (Figure IV-25).

Table IV-18

Chemical Analyses of Natural Brines South Fork of Wichita River - Area VIII

	Collection Point			
	Spring No. 1	Spring No. 2	Spring No. 3	River at Humble Lease Bridge Crossing
Date collected	9-7-60	9-7-60	9-7-60	9-14-60
pH	7.8	8.0	7.8	7.9
Specific Gravity, 20°C	1.0184	1.0064	1.0030	1.0204
Spec. cond. 25°C, micromhos/cm	12,600	16,000	12,400	40,000
Total alkalinity ($CaCO_3$)	120	100	148	88
Total hardness ($CaCO_3$)	3,080	3,280	2,960	4,000
Dissolved solids	10,000	12,600	9,600	29,500
Calcium (Ca)	864	880	816	1,200
Magnesium (Mg)	225	260	225	245
Sodium (Na)	2,380	3,250	2,250	10,500
Potassium (K)	21	23	19	60
Sulfate (SO_4)	2,325	2,600	2,325	2,900
Chloride (Cl)	3,900	5,280	3,800	15,800
Iron (Fe)	0	0	0	0
Boron (B)	3.0	3.9	2.4	3.4
Fluoride (F)	0.3	0.3	0.9	1.4
Bromine (Br)	30	20	40	20
Manganese (Mn)	0	0	0	0

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.


LEGEND
RANCH ROAD OR TRAIL
FENCE
GATE
PIPELINE
SPRING
SEEP AREA OR SALT PLAIN
INTERMITTENT STREAM
RIVER
WICHITA
OF
FORK
MIDDLE
HUMBLE PIPELINE STATION
OIL COMPANY-RANCH ROAD CROSSING
FARMERS CR.
STOCK POND
STOCK POND
SPRING 1
SCALE IN MILES
0
1/2
1
P
X

ARKANSAS—RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

MIDDLE FORK OF WICHITA RIVER
AREA X

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-25

Description of the Area

The salt spring and seep area occurs where the Dog Creek Shale and Blaine Gypsum interval of Permian age crop out. These formations consist of massive gypsum beds, red and gray gypsiferous shales, and dense, fractured, impure dolomites. In this vicinity, the river has eroded a valley about ½ mile wide and 100 feet deep through the Dog Creek and into the Blaine. The valley floor is essentially flat and partially filled with alluvial sands over which the river flows.

The regional dip in the area is to the southwest. The surface geology is essentially the same as in other salt areas in the Red River basin, consisting mainly of broken shale, dolomite, and gypsum.

The salt in the spring and seeps is probably dissolved from halite deposits in the Dog Creek-Blaine strata. This could be leached from the uplands on either side of the river by migrating ground water and carried to the river. Alluvial storage in this area appears to be very minor.

Brine Emission

The Middle Fork of the Wichita River becomes a perennial stream where the first seeps appear, about 6 miles above the oil company-ranch road bridge. The seeps appear along both sides of the stream and in a few places can be seen emerging from gypsiferous shale. This is at the base of vertical cliffs, which partially define the margin of the alluvial plain. During dry seasons, a salt encrustment forms on the seeps. Only one spring has been found in this area, and this has a concentration of 1,800 mg/1 and flow of 0.7 cfs.

Analyses of the area water are given on Table IV-19.

Salt Load

There is no station monitoring in this area directly, but a summary of reconnaissance data and an interpolation of data from Station 757 indicate that this area contributes about 50 and 10 tons per day of chloride and sulfate, respectively.

Table IV-19

Chemical Analyses of Natural Brines
Middle Wichita River - Area X

	Collection Point	
	Spring No. 1	Bridge Crossing
Date collected	----	----
pH	7.2	7.7
Spec. cond. 25°C, micromhos/cm	14,900	5,600
Total alkalinity ($CaCO_3$)	188	106
Total hardness ($CaCO_3$)	2,800	1,060
Dissolved solids	12,600	3,880.
Calcium (Ca)	850	336
Magnesium (Mg)	170	53
Sodium (Na)	3,200	1,000
Potassium (K)	30	10
Sulfate SO_4)	2,300	800
Chloride (Cl)	5,300	1,500
Silica (SiO_2)	13	10
Boron (B)	1.7	.66
Fluoride (F)	2.8	.15
Turbidity, Jackson units	25	25

All chemical analyses expressed as mg/l, except pH, unless otherwise indicated.

Manmade Salt Sources

General

Dissolved mineral solids (salts) are a waste byproduct of many of man's activities. Economic considerations dictate that the wastes be water-borne and disposed of in public waters. The following discussion deals with manmade sources of salt and gypsum in the Arkansas and Red River basins in order to provide an understanding of the relative magnitude and importance of this source of pollution.

Oilfield Brines

The largest and most important source of salt resulting from man's activities in these basins is the brine associated with oil and gas production and utilization operations. This source accounts for over 90 percent of the total manmade load in the study area. Table IV-20 demonstrates the magnitude of this waste disposal problem, and Figure I-10 "Areas of Petroleum and Natural Gas Production," shows the area covered by this industry in these basins.

The States in these basins produce 50 percent or more of the oil in the United States, and also have the largest reserves. About 17 percent of the United States oil production is in the Kansas, Oklahoma, and Texas portions of the Arkansas and Red River basins, which is the area of severest water pollution by salt.

The potential salt load from this source is enormous, and only the dedicated work of State and local agencies, and the cooperation of petroleum producers has kept the situation in its present good, though not completely satisfactory, condition.

An example of the reduction in salt loads which has occurred throughout the basins is shown in Figure IV-26, "Chloride Load and Streamflow in Canadian River near Whitefield, Oklahoma." The salt in this stream is believed to be essentially all from manmade sources, principally oil brines. The downward trend of salt load from about 1955 to 1962 is readily apparent, and is the result of reduction in oil brine releases both in Texas and Oklahoma.

Variable amounts of salt water are produced per barrel of oil, depending mainly on the age of the field. The extraction of natural gas also produces salt water in some cases. This appears to be a minor volume; the term "oil brine" is understood to include any brine produced from gas wells also.

In new fields or wells, little or no brine may be produced, but old, nearly depleted fields may yield as much as 100 barrels

Table IV-20

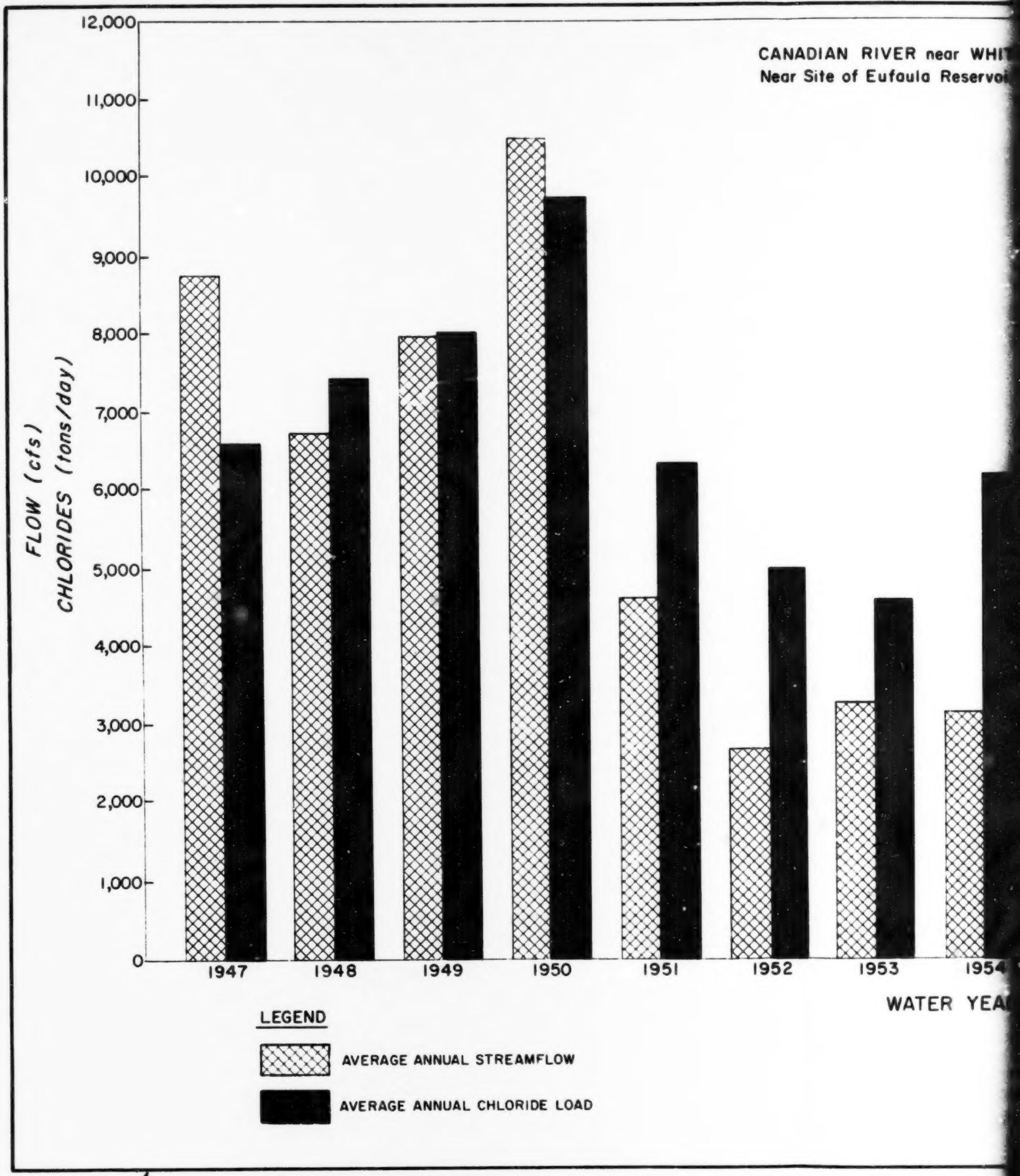
Oil Brine Production and Reinjection - 1961
Arkansas and Red River Basins

	Oil Production (mil. bbls.)	Total Brine Production Per Day (mil. bbls.)	Estimated Chloride in Brine * (T/D)	Brine to Pit or Direct to Stream * (bbls./day)	Brine to Pit or Direct to Stream * (T/D)	Percent Reinjected
Oklahoma	200	1.5e	50,000e	**	**	95+
Kansas	50	2.54	36,700	3,000	120	99.7
Texas	100	0.6e	25,000e	**	**	95+

e Estimated

* Information obtained from State agencies

** Information not available



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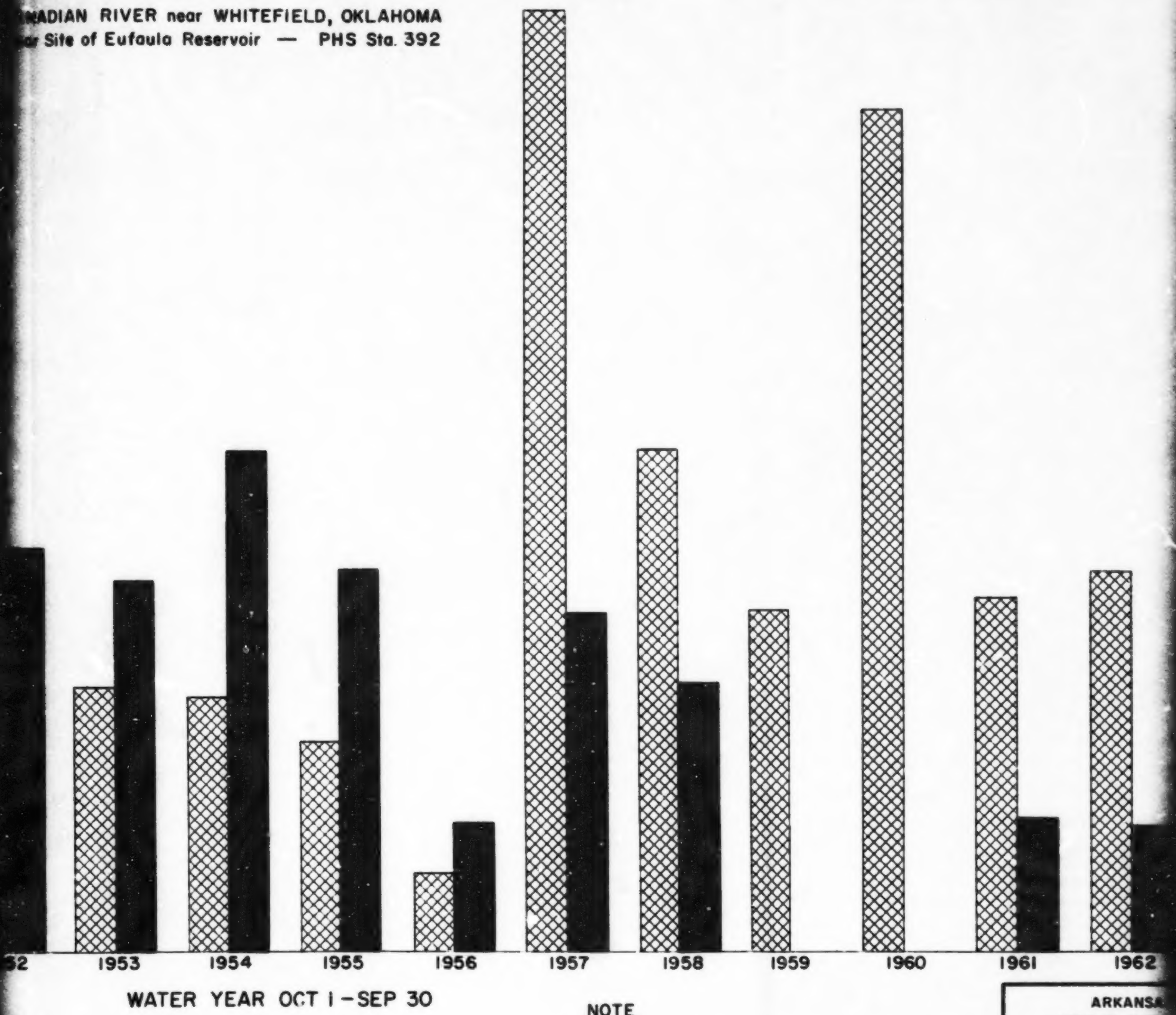
NADIAN RIVER near WHITEFIELD, OKLAHOMA
ar Site of Eufaula Reservoir — PHS Sta. 392



NOTE

1. STREAMFLOW FROM U.S. GEOLOGICAL SURVEY
2. DAILY SAMPLE CHLORIDE ANALYSIS BY U S GEOLOGICAL SURVEY 1947-1958; U.S. PUBLIC HEALTH SERVICE 1961-1962
3. CHLORIDE ANALYSIS FOR 1959, 1960 NOT AVAILABLE.

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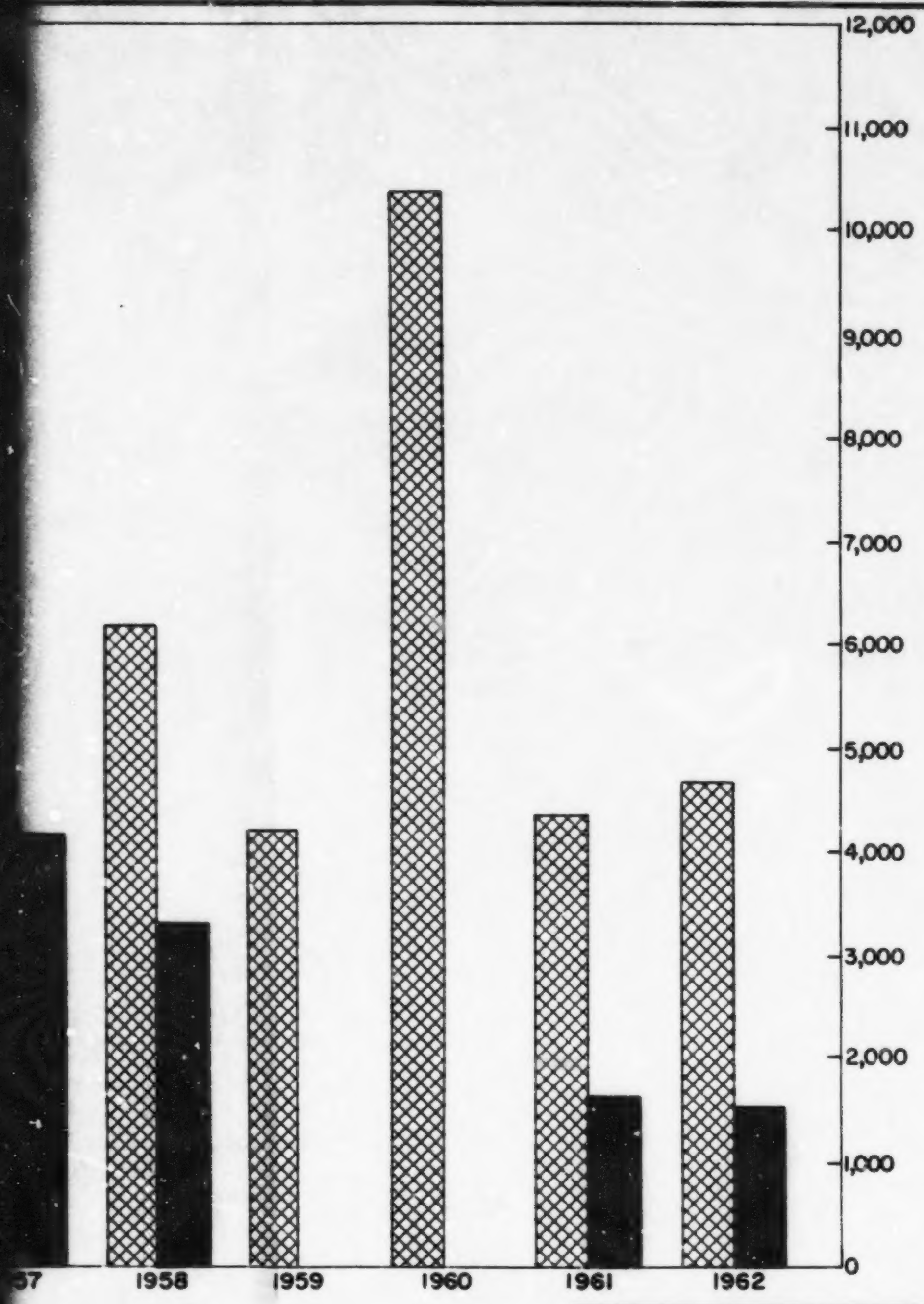

NOTE

1. STREAMFLOW FROM U.S. GEOLOGICAL SURVEY
2. DAILY SAMPLE CHLORIDE ANALYSIS BY U.S. GEOLOGICAL SURVEY 1947–1958; U.S. PUBLIC HEALTH SERVICE 1961–1962
3. CHLORIDE ANALYSIS FOR 1959, 1960 NOT AVAILABLE.

ARKANSAS–RED RIVER BASINS
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CHLORIDE LOAD AND STREAMFLOW

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE IV-26

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of salt water per barrel of oil. As shown in Table IV-21, concentration of salt in the brines also varies from weak to very strong, several thousand parts per million (ppm) to 200,000 ppm of chloride.

The oil brine analyses in Table IV-21 show that generally the chloride mol equivalent exceeds the sodium mol equivalent, and the calcium plus magnesium exceeds the sulfate. Thus, the oilfield brines contain calcium and/or magnesium which was combined with the chloride. This combination of compounds differs from the natural brines, where the ratio of chloride equivalents to sodium equivalents is about one, indicating combination with each other. The calcium and sulfate also appear to be combined with each other.

In many instances, oil brine reinjection into the producing formations increases the yield of oil (called secondary recovery or water flood) and enables economical recovery from formerly marginal or submarginal oilfields. In these cases, reinjection serves a dual purpose of waste disposal and improving oil recovery. There is no overall estimate of the amount of reinjection which serves this dual purpose. In Kansas, however, State Board of Health personnel reported that only 18 percent of the oil brines was reinjected into the producing formations, and the remainder is injected into other formations for disposal purposes only.

In the past 3 years, surface pit disposal of substantial amounts of oil brines has been discontinued, and the brine has been injected underground in the Red River basin in Texas. These improvements were brought about by the official pollution control actions of the Red River Authority of Texas and the cooperation of the oil producers.

Industrial Wastes

Possible industrial sources of salt-bearing wastes (other than oil and gas production) include four salt manufacturing plants and a chlorine-caustic plant, all of which obtain raw salt from underground sources. The salt load from all of these industries, which are located in Kansas, has been estimated as 70 tons per day average (1963) by Kansas State Board of Health personnel. It is not known if this load can be reduced, but it may be near its minimum.

About 3,000 tons per day of salt are produced in the four Kansas plants, while about 100 tons are extracted as brine in the chlorine plant. All of this salt is extracted from deep (about 300 feet) underground deposits. On the other hand, there are two smaller capacity (about 20 tons total) solar evaporation salt works using natural surface brines as raw material in western Oklahoma.

Table IV-21

Characteristics of Oilfield Brines
Arkansas and Red River Basins

Constituent*	Texas			Oklahoma			Kansas		
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
Specific Gravity	1.015	1.212	1.13	1.00	1.24	1.11	1.01	1.20	1.10
pH	2.8	7.6	5.3	----	----	----	----	----	----
Sodium (Na)	6,030	74,300	47,500	93	101,000	59,900	2,640	109,000	19,000
Calcium (Ca)	490	23,100	12,800	13	25,500	10,200	440	19,800	4,000
Magnesium (Mg)	160	3,550	2,180	13	6,340	1,940	220	10,900	1,400
Sulfate (SO_4)	2	960	175	0	3,620	270	0	4,100	1,100
Chloride (Cl)	10,500	162,000	110,000	460	193,000	102,000	8,600	177,000	40,000
Dissolved Solids (computed)	----	----	----	2,250	286,000	170,000	14,900	291,000	65,600

* All constituents are expressed as parts per million (ppm) except pH and specific gravity. Averages of Texas are Arithmetic-mean of all chemical analyses reported; Oklahoma and Kansas, Arithmetic-mean of about 10 percent of data. Averages are not weighted according to volume or weight.

This Table shows only the dominant constituents. Other materials such as carbonates, bicarbonates, barium, and strontium are included in the references, but their quantities generally were relatively insignificant.

Source: Bureau of Mines 27 28/
American Institute of Mining and Metallurgical Engineers 29/

Any part of their production that is distributed outside the basins removes it from these streams, but may contribute to a problem elsewhere. Distribution into lower basin reaches may be in a nondamageable area, but this does not alter the total salt load in the basins.

Liquefied petroleum gas storage operations are a potential source of salt water. Liquefied gas storage caverns are leached out of saltbeds and the saturated brine is saved and reused to displace or remove the liquefied petroleum gas. Losses during construction and operation of the 110 caverns in the basins are reportedly minor.

There are about 40 oil refineries (total capacity 958,000 barrels per day) in these basins. Many of them may use sulfuric acid and other mineral-like materials in their operation. No estimate was made of the amount of sulfate ion which may be wasted to the streams from this source, but the total chloride and sulfate problem appears insignificant. Sulfuric acid recovery and reuse is practiced in many of these refineries. Problem areas could be satisfactorily handled by State Pollution Control agencies.

There are three gypsum plants in these basins. These plants may expose additional gypsum rock at their mine quarry areas, in their stock piles, in waste piles, or in dust. This gypsum would be subject to leaching by rainwater, and might reach a watercourse. No study was made of gypsum processing methods, but it is believed that no wet processes are involved. This does not appear to be an important source of gypsum in the basin waters.

Other Sources

Municipal Domestic Use

All of the salt used in the household is expelled in domestic sewage. At a usage rate of 15 grams per capita per day, the total salt load from this source in these two basins is about 100 tons per day. This estimate includes chlorides from household bleaches.

Salt used for the regeneration of water softeners can not be estimated as accurately as the household use, but the following is believed to be a conservative estimate. This computation assumes a population of 5,500,000 for the basins above the lowermost stations in the two basins (Red River near Index, and Arkansas River at Van Buren, Arkansas), and further assumes that their entire household water supply will be softened. Assuming domestic water use as 100 gallons per capita-day and 100 mg/l hardness as $CaCO_3$, about 275 tons of salt would be used and returned in the basins per day. This domestic-municipal salt load is assumed to include the load from common light industries such as dairies which exist in most communities.

The total salt use for municipal-domestic activities averages 375 tons per day, or less than 1½ percent of the salt load measured at the lowermost stations in these basins. Assuming that this 375 tons per day salt is dissolved in the domestic-municipal sewage (100 gallons/capita/day), then the total daily flow accompanying this salt would be about 900 cfs.

Livestock

In 1958, 1,070,000 tons of livestock salt were used in the United States. With 8.1 percent of the United States livestock residing in these basins, about 250 tons salt per day results from this source. This salt is expelled at a uniform rate, but some may accumulate on land and reach the watercourse only after a rainfall. The volume of runoff containing this salt is not predictable, but would be large, as in the case of the flow containing domestic-municipal salt.

The total rise of salt for domestic-municipal and livestock is 625 tons per day average, or less than 3 percent of that in the streams.

Glossary of Selected Geologic Terms

Anhydrite: A mineral, anhydrous calcium sulfate, $CaSO_4$. Usually massive in evaporite beds where it is associated with gypsum, to which it changes. Anhydrite is harder than gypsum which contains two molecules of water of crystallization.

Anticline: An upfold or arch in the rocks. The beds dip outward in two or more directions from the crest.

Aquifers: Rocks or formations that are water-bearing.

Bed: The smallest division of a stratified series, and marked by a more or less well-defined divisional plane from its neighbors above and below.

Confluence: A junction or flowing together of streams; the place where two streams meet.

Conformable: Strata or groups of strata lying one above another in parallel order are said to be conformable.

Conglomerate: A rock made up of worn and rounded pebbles of other rocks, cemented together; a consolidated gravel.

Connate Water: Water entrapped in the interstices of a sedimentary rock at the time the rock was deposited.

Consolidation: Any or all of the processes whereby loose, soft, or liquid earth materials become firm and coherent.

Deltaic deposit: An alluvial deposit at the mouth of a river. Usually more or less triangular in form.

Ephermeral stream: A stream, or portion of a stream, which flows only in direct response to precipitation. Its channel is at all times above the water table.

Fluviatile: Sedimentary deposits laid down by a river or stream.

Formation: 1. In geology, any assemblage of rocks which have some character in common, whether of origin, age, or composition. 2. As used by USGS, the ordinary unit of geologic mapping consisting of a large and persistent stratum of some one kind of rock.

Ground Water: Water in the zone of saturation; also called phreatic water.

Group: A local or provisional subdivision of a series, based on lithologic features. It is usually less than a standard series and contains two or more formations.

Gypsum: Hydrous calcium suifate, $CaSO_4 \cdot H_2O$. A common mineral of evaporites.

Alabaster: A fine-grained, compact variety, white, shaded, or tinted.

Gypsite: An incoherent mass of very small gypsum crystals or particles, which has a soft, earthy appearance; contains various impurities, generally silica or clay.

Satin Spar: A fine, fibrous variety which has a pearly, opalescent appearance.

Selenite: A variety which occurs in distinct crystals or in broad folia.

Halite: Rock salt. A mineral NaCl. A common mineral of evaporites.

Intermittent stream: Streams which flow only part of the time, as after a rainstorm, during wet weather, or during only part of the year.

Karst topography: Irregular topography, developed by the solution of surface and ground waters, is known as Karst topography.

Lacustrine deposits: Deposits formed in the bottom of lakes.

Limestone: A bedded sedimentary deposit consisting chiefly of calcium carbonate ($CaCO_3$). Limestone is the most important and widely distributed of the carbonate rocks and is the consolidated equivalent of lime, mud, calcareous sand, or shell fragments.

Lithology: A term used to indicate the origin and properties of rocks.

Negative feature: A depression or basin which, when contoured, is closed.

Nose: A half-developed anticline. One in which one end is open and without closure.

Permian: Formerly the last of three epochs in the carboniferous period. Since advanced to period rank. Now referred to as last of seven periods in Paleozoic era. Also the series of strata deposited during that epoch.

Pleistocene: The earlier of the two epochs comprised in the Quaternary period, in the classification generally used. Also called Glacial epoch, and formerly called Ice age, Post-Pliocene, and Post-Tertiary. Also the series of sediments deposited during that epoch, including both glacial deposits and ordinary sediments.

Pliocene: The latest of the epochs comprised in the Tertiary period, in the classification generally used. Also, the series of strata deposited during that epoch.

Quaternary: The latest period of geologic time. The later of the two geologic periods comprised in the Cenozoic era, in the classification generally used. Also the deposits formed during that period. It is subdivided into Pleistocene and Recent epochs or series.

Red beds: Red sands and shales with thin limestones and much gypsum, widespread over western United States, which range in age from late Pennsylvanian to Jurassic, but are largely Permo-Triassic.

Sandstone: Consolidated rock composed of sand grains cemented together.

Seep: A spot where water or petroleum oozes out slowly; a small spring.

Seepage: The percolation of water through the surface of the lithosphere, or through the walls of large openings in it, such as caves or artificial excavations. The term infiltration has essentially the same meaning.

Series: Stratigraphically, the term is applied to the main subdivisions of systems.

Shale: A laminated sediment, in which the constituent particles are predominantly of clay grade.

Siltstone: A very fine-grained sandstone, the particles of which are predominantly of silt grade.

Spring - artesian: One whose water issues under artesian pressure, generally through some fissure or other opening in the confining bed that overlies the aquifer.

Spring - contact: One whose water flows to the surface from permeable material over the outcrop of less permeable, or impermeable, material that retards or prevents the downward percolation of the ground water, and thus deflects it to the surface.

Spring - depression: One whose water flows to the surface from permeable material simply because the surface extends down to the water table.

Spring - fracture: Fracture springs and tubular springs are springs whose water flows from relatively large openings in rocks. The term fracture spring is used where the opening or openings, consist of joints or other fractures. The openings in these springs are more or less sheet-like. The term tubular spring is used where the opening, or openings, consist of more or less rounded channels, such as solution passages in limestone or gypsum, or natural tunnels in basaltic lava.

Spring - gravity: One whose water does not issue under artesian pressure, but which is due to an outcrop of the water table.

Spring - seepage: A seepage or filtration spring is one whose water percolates from numerous small openings in permeable material. Many of these springs have a very small discharge, but others yield freely. The term seepage spring is often limited to springs with small discharge; the term filtration spring may be applied without limitation as to yield.

Strata: Plural of stratum.

Stratum: A single sedimentary bed or layer, regardless of thickness (Shrock).

Stratigraphic: Pertaining to the strata, or the science of the strata.

Structure: In general, the attitude of the rocks and the features which determine that attitude, as stratification, faults, anticline, syncline, terraces.

Syncline: A trough in the rock beds; a structurally low point toward which the rocks dip; a structural basin.

Thalweg: The natural line of drainage over the surface of a stream along which the flow takes place.

Triassic: The earliest of three periods of the Mesozoic era. The rocks of this age in the United States are largely terrestrial. "Red Beds" are characteristic.

Unconformable: Having the relation of unconformity to the underlying rocks in immediate order of age, and in parallel position.

Unconsolidated: Opposite of consolidate.

Undergound thalweg: The natural line of drainage over the underground surface of bed rock along which the underflow of a stream takes place.

Vug: A cavity in the rock, usually lined with a crystalline incrustation.

Source: American Geological Institute 30/

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V. WATER QUALITY OBJECTIVES

In any program where improvement of degraded water is undertaken, quality objectives or goals are required to enable sound planning of abatement programs and works and evaluation of the related benefits. The objective must be realistic and subject to revision, based on new technical and economic factors. The major contaminants in these basins are minerals, mostly salt. However, dissolved solids, chlorides, and sulfate are the only constituents considered in this discussion. These are major constituents of both natural salt sources and oilfield brine.

The natural brines are not the responsibility of any agency or individual, as they now represent a major pollution source beyond the normal jurisdiction of the State pollution control agencies. Since these natural brines cause interstate pollution and the water quality degradation is regional and broad, natural brine control is a responsibility of the U.S. Government as set forth in the Federal Water Pollution Act, as amended. 1/ Thus, the adoption of water quality objectives or standards for brine reduction will be a mutual responsibility of the basin States and the U.S. Government.

Municipal

Of the many diverse needs for and uses of water, domestic-municipal usage is one of the larger users, and it has the highest priority of water use. The drinking water standards of the States and the Public Health Service 2/ recommend that chlorides should not exceed 250 mg/l, sulfates 250 mg/l, and dissolved solids 500 mg/l, where other more suitable supplies are, or can be made available. The effects of these constituents, and the constituents which are their companions, are shown in Table V-1. From these data and standards, it would appear that the drinking water standards are a good single objective for the development of a control program. The objective, or limit, should be qualified, however, or modified with a reasonable factor of safety to allow for normal variations in the salt loads and flows and large accidental releases of salt. Furthermore, these standards are suggested upper limits and recommendations have been made that "ideal water quality" for municipal use should not contain over 200 mg/l dissolved solids and 80 mg/l hardness (as $CaCO_3$) when delivered to the user.

At most of the points of use in the study area, the chloride and sulfate concentrations exceed 250 mg/l. To meet the 500 mg/l drinking water standards for dissolved solids, chloride and sulfate cannot be 250 mg/l each. At these concentrations, and assuming that the chloride is combined with sodium as salt, and the sulfate with calcium as gypsum, dissolved solids from these compounds would be only about 750 mg/l. A sulfate concentration of 250 mg/l, and chloride of 100 mg/l would give 500 mg/l of these dissolved solids. Therefore, to attain a water quality which is most suited to the economic growth and development of the area, the chloride should be reduced to a maximum of 100 mg/l and, preferably, lower if possible. In practice, the reduction of the chloride content from its sources will also reduce the induced sulfate load on the stream.

Table V-1

Effects of Common Inorganic Ions in Waters

Impurity	Effects	Recommended Limit
Sodium (Na)	Detrimental to Cardiac Patients	20 mg/l
Chloride (Cl)	Causes disagreeable taste	250 mg/l
	Industrial process water	20-250 mg/l*
Sulfate (SO_4)	Causes disagreeable taste	250 mg/l
	Acts as a cathartic	600-1000 mg/l
Sum of Calcium (Ca) & Magnesium (Mg)	Produces Excessive Hardness	100 mg/l as $CaCO_3$

*Industrial threshold concentrations of Cl by use: Carbonated beverages - 250 mg/l; food equipment washing - 250 mg/l; boiler makeup - 210 mg/l; paper making - 75 to 200 mg/l; textile processes - 100 mg/l; and sugar making - 20 mg/l.

Source: Public Health Service 2/, American Heart Association 3/, California Water Pollution Control Board 4/, and E. B. Phelps 5/

Industrial

Residents of the basins would like to have their surface waters essentially devoid of minerals, especially near their community. This desire is derived principally from the theory that the available quantities of such high quality water would exert a strong and favorable influence on economic growth.

Industrial usage is varied and large, with much of the water being used for cooling, which can be done with poor quality water. However, to attain a water quality which is attractive to industry, and since the source for most municipal and industrial use will be the same, the chloride content should be reduced to the same level as for municipal use, 100 mg/l or lower. The recommended mineral limits by a few of the major industrial water users are shown in Table V-2. The industrial threshold of chloride by use range from

20 to 250 mg/l. The recommended chloride reduction to 100 mg/l is well within these limits.

Table V-2

Recommended Limits of Impurity to Protect Specific Uses

Impurity	Recommended Limit (mg/l)					
	Drinking Water	Irrigation	Paper	Food	Boiler	Steel
Dissolved Solids	500	350-700	200-500	850	50-3000*	
Sulfate	250	200-480				
Chloride	250	70-178	75-200	20-250	210	175
Sum of Ca & Mg as $CaCO_3$	100		100-200	10-250	2-80*	50

*Exact figure is a function of pressure (i.e.: higher figure corresponds to low pressure).

Source: Public Health Service 2/, and California Water Pollution Control Board 4/

Irrigation

The water utilized for irrigation of crops in the study area is at present the largest single water use. Water quality is an important factor in evaluating the usefulness of water for irrigation. There are, however, many aspects involved in evaluating the effects water of any given quality will have on plant growth.

Three criteria commonly used in establishing general suitability of water to be used for irrigation of crops are:

1. Trace elements - Expressed as concentration of toxic ions.
2. Major cations and/or anions - Expressed as ionic concentration or the ratio of one ion to others.
3. Salinity - Expressed as total concentration of dissolved salts or the ability of water to conduct electric current (ohms per centimeter @ 25° C-$\text{ECX}10^{n}$).

No exact limit can be set for the maximum permissible salt content of irrigation water, since such limitation depends greatly on the kind of salt in solution, soil type, subsoil drainage characteristics, crop tolerance, and farm management practices. In general, however, dissolved solid concentrations in soil solutions are 3 to 10 times higher than those of the irrigation water. In most cases, dissolved solids concentration for irrigation waters of acceptable quality will range between 100 to 2,000 mg/l. 6/ These concentrations are equivalent in most natural waters to electrical conductivity (EC) readings of 140 to 2,800 micromhos.

A general classification of irrigation waters, assuming average soil types, cropping patterns, and farm management, is given according to quality in Table V-3.

Table V-3

Classification of Irrigation Water

Class*	Dissolved Solids (mg/l)	Dissolved Solids $\text{ECX}10^{6}$	Sodium (%)	Chlorides (mg/l)	Sulfates (mg/l)	Boron (mg/l)
1	<700	<1,000	<60	<178	<480	<0.5
2	700-2,100	1,000-3,000	60-75	178-355	480-960	0.5-1.0
3	>2,100	>3,000	>75	>355	>960	>1.00

*Class 1 - Excellent to good, or suitable for most plants under most conditions.
Class 2 - Good to injurious, harmful to some plants under certain conditions of soil, climate, and practice.
Class 3 - Injurious to unsatisfactory, unsuitable under most conditions.

Source: California Water Pollution Control Board 4/, and
U.S. Department of Agriculture 7/

While the irrigation water classifications are generally based on the specific conductance of the water, Table V-3 gives a relationship between the specific conductance and mg/l of chlorides. The quality objective of 100 mg/l is well within these criteria of Class 1 irrigation water.

Other

In establishing a water quality objective, the out-of-stream uses are generally all that are considered. However, there are many instream uses that can be improved with a proper quality objective. By lowering the salt content of the stream there will be a tendency for a change to occur in the type of plant life on the banks of the stream. While the high salt tolerant plants will not disappear, plants of a low tolerance can be induced to grow.

Recreational aspects will be improved due to less maintenance on boats and other recreation facilities.

A change in the type of fish life will occur, with a suitable habitat for low salt tolerant fish.

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VI. PROPOSALS FOR CONTROL OF MINERAL POLLUTION

General

As previously pointed out (Chapter II, Volume I of this Appendix), mineral wastes resulting from man's domestic and municipal activities in the Arkansas-Red River basins are minor and of low concentration (96 mg/l). The 235 tons of salt attributed each day to these activities are dissolved in about 900 cubic feet per second (cfs). On the other hand, natural and oilfield brines account for 95 percent of the basins' mineral pollution and are contained in less than 1 percent of the average total streamflow in the basins. Thus, it would seem unfeasible to be concerned with the reduction of minor dilute sources, but instead deal with the major contributors--natural and oilfield brines. The following is concerned with general ideas for the prevention of stream pollution resulting from dissolved minerals and the discussion of other water conservation problems.

Reduction of Natural Mineral Pollution

Natural salt loads reaching streams in these basins must be reduced greatly to achieve any desired degree of water quality improvement. Numerous procedures for this reduction have been suggested. These involve dams, dikes, storage basins, canals, and pumping systems for the collection, storage, suppression, and transmission of natural brines.

Although the engineering design and construction of flood control, navigation, irrigation, and power projects are well developed, the control of large volumes of brine is unique and untried. The leakage of 1 cfs through power or flood control projects would ordinarily be insignificant, however, this flow of saturated brine would contain 850 tons of salt each day. This flow, with an average concentration of the basins' natural brines, would contain about 150 tons of salt each day.

The Corps of Engineers is studying possible natural brine control methods. Their report will be based in part on field tests of some of the proposals and will include details of design of each method either alone or in combinations.

Some of the proposals call for the concentration of part of the brine. This could be accomplished by any practical method, such as evaporation or electrodialysis.

Subsurface Disposal of Brines

Currently, many of the brines from oil and gas production in these basins are being reinjected into formations from which oil and gas have been extracted. Similar subsurface disposal of natural brines may be possible if suitable geological formations underlie or are near natural brine sources and the volume of natural brines is not too great. Since natural brines are to be injected into formations different from their source, it is important that these formations be chemically and physically able to receive the mineralized waters.

The University of Oklahoma conducted a preliminary study of the potential for subsurface disposal of natural brines in both basins. It was concluded that this method offered promise. Subsurface strata of large capacity were available and disposal costs seemed reasonable. Table VI-1 shows a summary of the costs and pertinent data for injection equipment, operation, well drilling, and casing. The disposal areas considered were within a 20-mile radius of the salt source. The study was limited to shallow strata of about 5,000 feet, and the desirability of investigating deeper strata in the southwest portions of the basin was recognized. 1/

James A. Lewis Engineering, Inc., of Dallas, conducted a preliminary investigation of the potential for subsurface disposal of natural brines into deep formations in the upper Red River basin. Attention was directed mainly to the Arbuckle (or Ellenberger) Formation which has a great capacity for economical waste assimilation in Kansas and northern Oklahoma. Conclusions of the study were that this method had promise for some areas; but more basic information is needed. A disposal test was recommended at Estelline Spring. (Area V.) 2/

Westco Research, of Dallas, has conducted a feasibility study on the subsurface disposal of brines from tributaries of Elm Fork of the Red River. The company proposed a 4-phase, 18-month program of brine injection to the Bureau of Reclamation, the cost of which was estimated at $490,000. Westco would continue the program after an 18-month period for an annual cost of $70,000. The operation would include well drilling and development, testing, brine collection, transportation, and injection.

Collection and Permanent Storage of Natural Brines

Brines may be collected and stored in off-channel impoundments (which may require collection and diversion) or in on-channel storage, as in the case of the Great Salt Plains. Here, fresh water upstream from the plains could be diverted downstream from the reservoir. Brines would be retained in the Great Salt Plains Reservoir, and the flood control capacity replaced by other means.

Table VI-1

Estimates* of Natural Brine Disposal Costs by Subsurface Injection

(Includes all capital, amortization, and operation costs)

Area and Brine Source	Brine Volume (cfs)	Chloride (tons/ day)	No. of Disposal Wells	Years Storage (est.)	Cost per Million gal.	Cost per Bbl. (42 gal.)	Chloride (cost per ton)	Total Annual Cost ($1,000)
I - Great Salt Plains	5	1,400	13	80 - 160	$445	1.8¢	$0.90 - $1.81	$525 - $1,050
II & III - Big Salt Plains and Little Salt Plains	12	3,600	6	200 - 300	448	1.8	0.22 - 0.35	321 - 512
IV - Salt Creek of Cimarron River	1	225	1	2,700	426	1.7	1.38	106
V - Estelline Spring	5	375	5	750	533	2.2	3.97	507
VI - Elm Fork Springs	1	250	4	1,000	415	1.7	0.90	98.4
VII, IX, and X - North Wichita River, Middle Wichita River and Pease River	5	600	4	1,000	550	2.3	4.77	522
VIII - South Wichita River	2	200	4	250	502	2.1	8.70	477

* SOURCE: Deep Subsurface Disposal of Natural Brines in the Arkansas and Red River Basins, University of Oklahoma, Study for Public Health Service.

It is estimated that the reservoir, with minor modification, has a brine storage capacity of 100 years or more at the present rate of brine emission.

Elimination or Reduction of Fresh Water Recharge to Subsurface Salt Deposits

Rainfall, in part, penetrates the ground to some geological formation through which it moves until coming into contact with salt deposits. Part of the salt is dissolved to form a brine which may appear as a salt spring or seep at the ground surface at a lower elevation. This source of brine can be controlled or eliminated by changing the direction of flow to avoid contact with salt, or by removing some of the hydrostatic head so that polluted waters can no longer reach the surface. This can be accomplished by lowering the elevation of the ground water permanently or by the installation of barriers which are impervious to the passage of fresh recharge water. This method also provides for some land preservation.

Elimination or Reduction of Brine Flows by Hydrostatic Pressure or Plugging

Natural brine springs are hydrologic phenomena which appear to have a low static head causing them to flow. Inundation of these springs may impose enough back pressure to stop or reduce the brine flow. This method of control is referred to as plugging. The Corps of Engineers is conducting two tests to ascertain the practicability of this method and obtain basic data on the effects of such inundations. These tests include a dike around Estelline Spring to impose a 6-foot static head, and the imposition of a 6-to 10-foot head on a large spring on the South Wichita River.

Transportation to Nondamaging Disposal Site

The disposal of brines may be accomplished by collecting and transporting to areas having a large salt assimilative capacity, such as the Gulf of Mexico, or possibly the lower Mississippi River. A pipeline or canal for this purpose could also serve to remove other highly concentrated, refractory wastes from manmade as well as natural sources.

Utilization of Salt

Inquires made to The Chlorine Institute, Inc., of New York, The Salt Institute of Chicago, and several large, individual salt producers and users lead to the conclusion that extensive utilization of natural brines for the production of salt is a remote possibility. Even if present day demands or prices stimulated removal, the amount extracted would be a small part of the amount being discharged to the streams.

About 3,000 tons of salt are produced each day from underground salt deposits in the Hutchinson area of Kansas. It could be feasible to replace this salt with natural brine from the Big and Little Salt Plains about 120 miles away on the Cimarron River in Oklahoma.

The quality of salt from these natural sources is about the same as that in the Hutchinson salt plants, where the salt is about 97 percent NaCl and about 2.5 percent $CaSO_4$, with the remainder being magnesium chloride or sulfate and inerts. Weaker brines in the study area contain a higher percentage of $CaSO_4$, up to 10 percent.

Alternate Supplies and Blending

There are no known significant natural brine sources east of a line running roughly from Wichita Falls, Texas to Wichita, Kansas, nor have natural brine sources been found in the Canadian or Washita River basins. Hence, there are large amounts of water in the Arkansas and Red River basins without significant natural pollution, although contaminated to varying degrees by oilfield brines. West of the central basins, the major sources of natural brines, chlorides are not a problem; however, large natural deposits of gypsum result in high sulfate concentrations and water of an inferior quality.

In the Arkansas River basin, the Verdigris, Neosho, Poteau, and Illinois Rivers contain water with average chloride concentrations less than 100 mg/l. Sulfates are correspondingly low.

In the Red River basin a similar situation prevails--low solids concentrations in tributaries in the eastern part, high chlorides and sulfates in the middle portion, and high sulfates only in the west.

Streams, or groups of streams, in the affected portions of the study area having low dissolved mineral concentrations are shown in Table VI-2, along with concentration values and flows.

Sufficiently improved quality may be realized by transferring and blending high quality waters from the eastern part of the basins with those of high mineral content in the central part. If eastern waters are available for transfer at an early date, a blending plan would increase the total volume of usable water.

A water supply of acceptable quality can be extended or the cost of procurement reduced by mixing high mineral waters with low mineral waters. These techniques, however, will not improve overall water quality in the basins, and will not satisfy the objective of providing abundant quantities of good water for the attraction

Table VI-2

Major Streams of Suitable Quality

Stream and Location	1961-62 Water Year		Long-Term Records		
	Dissolved Minerals Concentration (mg/l)	Average Streamflow (cfs)	Flow Record (years)	Average Flow (cfs)	Minimum Flow (cfs)
Arkansas River Basin					
Poteau River near Wister, Okla.	No Data	965	24	1,188	200
Illinois River near Gore, Okla.	No Data	1,681	24	1,575	63
Grand Neosho River near Ft. Gibson, Okla.	No Data	10,947	12	7,150	1,158
Verdigris River near Inola, Oklahoma	218	7,470	18	4,483	297
Chickaskia River near Blackwell, Okla.	No Data	595	27	493	71
Ninnescah River near Peck, Kansas	No Data	631	25	553	186
Little Arkansas River near Valley Center, Kansas	182*	493	40	252	25
Red River Basin					
Washita River near Durwood, Okla.	571	1,245	34	1,526	391
Little Wichita River near Henrietta, Texas	271	78	9	134	45
Beaver Creek near Waurika, Okla.	522	164	9	152	39
Cache Creek near Walters, Okla.	273*	246	24	188	13
North Fork of Red River above Lake Altus	1,220*	216	18	138	18

* One year or less of quality data.

and stimulation of industrial and agricultural growth and extensive general development of the basins.

Oil and Gas Brines

Oil and gas are depletive resources. For the past 30 years or more, new discoveries in the United States have kept pace with production and consumption; however, with increasing costs of exploration and production, other fuel sources may become competitive and a decrease in oil and gas production can result. The depletion of reserves and the anticipated life of petroleum extraction cannot be predicted with any degree of accuracy. According to the 1962 report of the Independent Petroleum Producers Association of America ("The Oil Producing Industry in Your State"), the proven U.S. oil reserves at present production rates are sufficient for only 13 years, assuming no more reserves are found, and recovery methods remain unchanged.

Upon exhaustion of the reserves and the cessation of oil production, all salt water production and reinjection practices will be eliminated and secondary, or indirect salt water pollution such as subsurface leakage through defective, abandoned wells also will end. Actual reduction of salt content in the watercourses, however, will be gradual and will depend upon the rate of leaching of the deposits.

It is possible that some of the natural salt source control works which may be installed can also be used for oilfield brine disposal. This will be an individual problem and must be based on economic feasibility. For example, a pipeline to carry the 15 natural salt sources to the Gulf of Mexico could be designed for transportation of oil brines also.

It has been pointed out that the ratio of salt to oil increases with the age of the producing field. This is caused by the replacement of oil in the reservoir by salt water and entry of more salt water into the well casing. It appears that regulation of the pump and casing would keep it in oil only, thereby eliminating excess production of salt water. Since wells are generally deep, this is a costly operation and it is cheaper to produce and dispose of brines than to regulate the pump and casing.

Other Analyses

Sulfate Control

As previously indicated, most of the sulfate load is from natural sources; the accumulation of sulfate in water is gradual and spread over large areas. Removal or control of the natural salt sources will also remove some of the sulfate load. The amount of accompanying sulfate removal depends greatly on the method used for natural salt control but is expected to be between 10 and 20 percent. If control structures are built near the points of brine emission sulfate removal would be low. On the other hand, structures built downstream would remove more sulfates because a greater area contributing sulfates would be controlled.

There are no known means for further, feasible reduction of sulfates by preventive measures. Special consideration of this problem is desirable. It may also be desirable to determine the basic fundamentals of natural gypsum dissolution. The following are possible suggestions for practical field observation or study.

1. Minimize the solubility of gypsum by treatment of outcrops or exposures, especially those in watercourses. Application of an impervious coating or barrier may be helpful.

2. Construct special channels and drains to minimize contact time of water and the gypsum.

3. Barium carbonate application at the inlet of a reservoir would precipitate both the calcium and sulfate in the reservoir. It should be determined if the barium sulfate can be recovered for conversion and reuse. There may also be biological means for accelerated, large-scale sulfate degradation and possible recovery.

Stratification

It has been observed that, under proper conditions, waters of sufficiently different densities may form and maintain separate and distinct layers. Density differences may result from differences in temperature or mineral concentrations.

In 1958, North Texas State University, Denton, Texas, conducted a stratification study of Lake Texoma to ascertain if the degree and extent of stratification lent itself to a practical means for separation of better quality waters from the poorer. Although stratification was observed, mineral concentrations were not sufficiently different to enable or justify separation. The Washita arm of the Lake contains acceptable quality water.

Priorities of Pollution Control

Water needs and supplies are not uniform throughout the critical portions of these basins. Some communities or areas have lower volumes and poorer quality than others. Also, some areas are more vulnerable to drought or have unsuitable emergency supplies. To provide relief for the most critical areas first, the following schedule for natural salt source abatement is suggested:

1. Sources on the three tributaries of the Wichita River.
2. Sources on the Elm Fork of the North Fork of the Red River.
3. Estelline Spring.
4. Jonah Creek.
5. The Big and Little Salt Plains on the Cimarron River.
6. The Great Salt Plain on the Salt Fork of the Arkansas River.

Criteria used in this priority list are the immediacy of water needs, volume of water improved, and degree of improvement by control of a single source.

Among the larger areas to be benefited by this schedule are: Wichita Falls and Denison, Texas; Shreveport and Alexandria, Louisiana; and Tulsa and Oklahoma City, Oklahoma.

The Corps of Engineers is operating control works to reduce or eliminate brine releases from Estelline Spring and a spring on the South Wichita River. If either or both of these relatively simple and inexpensive works are successful, up to 10 percent reduction in the salt concentration in Lake Texoma and at Denison, Texas may be realized.

State Water Pollution Control Programs

All the States in these basins have pollution control legislation and administration programs (including oil and gas brines) to control water pollution. In general, the interest and sometimes the legal authority are divided among several State agencies which have a direct interest either in the quality of the water, in the development of the water resources, or in the development and control of an industry whose waste material may degrade the water. In all of these States, there are voluntary and/or legally authorized cooperation and coordinated programs by the agencies involved. Legislative authority in all of the basin States appears adequate.

The improvement and maintenance of satisfactory water quality for maximum usage throughout these basins will require abatement and control of both manmade and natural brines. Suggested pollution control program goals, by State and subbasin area, are shown in Table VI-3.

Table VI-3

Suggested Salt Load Reduction Program in Arkansas and Red Rivers
(exclusive of primary and secondary salt sources)

State and Basin	Subbasin and Area	Present (1961-1962) Salt Load*	Load Reduction*	Suggested Maximum Permissible Load After Control Program*
Kansas Arkansas River	Grand Neosho River	165	65	100
	Verdigris River	330	230	100
	Walnut River	455	355	100
	Arkansas River & Tributaries - Great Bend to Arkansas City	850	600	250
Oklahoma Arkansas River	Salt Fork of Arkansas River	350	250	100
	Cimarron River	575	425	150
	Verdigris River	1,330	1,030	300
	Canadian River	2,360	2,060	300
	Arkansas River - Arkansas City, Kansas to Tulsa, Oklahoma	450	300	150
	Arkansas River - Tulsa to Van Buren, Arkansas	845	645	200
Red River	Washita River	265	215	50
	Red River above Lake Texoma	520	470	50
Texas Arkansas River	Canadian River	320	310	50
Red River	Wichita River	360	310	50
	Beaver Creek (Wichita River)	130	105	25
	Red River and Tributaries above Lake Texoma	1,360	1,060	300

* Tons NaCl/day.

All of the States in the two basins are engaged in pollution control activities. Programs vary among the basins' states, ranging from comprehensive basin-wide studies to specific individual pollution source investigations, with corrective steps taken as indicated. Summarized below are brief statements concerning administrative agencies, and programs as defined by statutory authority.

Colorado

The State Department of Public Health has authority to investigate and control the courses of epidemic and communicable diseases affecting the public health; abate nuisances when necessary to eliminate sources of epidemic or communicable diseases; establish and enforce minimum general sanitary standards as to the quality of water supplied to the public, and as to the quality of the effluent of sewage system and trade wastes discharged upon the land or into the surface or ground waters, and advise with municipalities, utilities, organizations and individuals concerning the methods or processes believed best suited to provide the protection or purification of water and the treatment of sewage and trade wastes to meet such minimum general sanitary standards; establish sanitary standards, and make sanitary sewerage and health inspection and examinations for charitable, penal, and other public institutions; and enforce the public policy of the State with regard to the pollution of the waters of the State by human excreta (Chapter 66-1-7, 1955 Cumulative Supplement). [3]

The Fish and Game Commission has the responsibility of protecting fish life in public waters. No sawdust, tailings, or other deleterious or poisonous substance may be allowed to run or pass into or pollute any public waters containing fish, or deposited or left where it may be carried by natural causes into such waters in such quantities as to destroy or be detrimental to the fish or spawn therein (Chapter 62-5-13). [3] Every dam or other artificial obstruction, every placer mine, mill, refuction plant or other artificial obstruction, or other industrial enterprise, constructed, maintained or operated in violation of the Act, is declared unlawful, and a continuing public nuisance, and the same may be enjoined or abated or its objectionable features modified (Chapter 62-5-14). [3]

The Oil and Gas Conservation Commission is authorized, among other things, to require the drilling, casing, operation, and plugging of wells in such manner as to prevent the intrusion of water into oil or gas stratum, the pollution of fresh water supplies by oil, gas or salt water or brackish water, and requires measures to prevent blowouts, explosions, cave-ins, and seepage (1955 Cumulative Supplement, Chapter 100-6-15 (1) (c)).

There are other miscellaneous statutory provisions protecting surface and subsurface waters.

It is unlawful to empty or flow oil, petroleum, or other oleaginous substance into any of the waters of the State, or deposit or cause the same to be deposited at such a distance that it may be carried into such waters by natural causes. Violation is a misdemeanor, and upon conviction is punishable by a fine not exceeding $1,000 or imprisonment in county jail not exceeding six months, or both (Chapter 40-12-23). [3]

New Mexico

The New Mexico State Board of Public Health has the primary function of controlling water pollution. It establishes policies, rules and regulations for the State Department of Public Health (Section 12-1-6). [4]

The Oil Conservation Commission is authorized to make rules and regulations for, among other things, the prevention of pollution of waters from oil and gas wells (Section 65-3-11). [4]

The State Game Commission is authorized to make rules and regulations for, among other things, the protection of game and fish (Section 53-1-11). [4] It is further authorized to protect spawning waters, or to prevent undue depletion of fish (Section 53-1-8). [4]

Miscellaneous statutes also protect water supplies. It is unlawful to cast the dead body of any animal or fowl or any refuse matter into any running stream, spring, reservoir or watercourse, or to run or empty any sewer or other foul substance into the same, or in any other manner pollute such waters so as to render it offensive or dangerous to the health of the inhabitants of any community or of any person having the right to use the same for drinking or domestic purposes, or so as to render such waters unfit for watering stock. The polluting of the waters in the manners specified herein is a public nuisance. In addition to the fine and/or imprisonment which may be imposed for a violation of this section, the court may direct the sheriff or constable to remove such nuisance at the expense of the person creating it (Sections 40-35-11, 12, 13). [4]

It is unlawful for anyone wilfully to poison any spring, well or reservoir of water (Section 40-6-11). [4]

All pipelines carrying oil, natural gas, or their products which pass through or over streams, streambeds, or bodies of water, must be so constructed, maintained and operated as not to pollute such waters (Section 65-4-5). [4]

Kansas

The Kansas State Board of Health has the primary function of controlling water pollution. The Board is authorized to make rules and regulations necessary for the protection of the surface and subsurface water from pollution by oil, gas, salt water injection wells, or underground storage reservoirs, and to govern the disposal of domestic, industrial and sewage wastes by municipalities, corporations, companies, or individuals, as well as for the collection of samples and analysis of water furnished by anyone to the public. The analysis is made at the Water and Sewage Laboratory of the Board in the University of Kansas (1955 Supplement, Section 65-171d (as amended by Chapter 333, Laws of 1957; Sections 65-156, 65-157). [5]

The board is also empowered to publish approved minimum standards of design, construction, and maintenance of sanitary water and sewage systems (1955 Supplement, Section 65-171h). [5]

The State Water Resources Board is authorized to work out a plan of water resources development for each watershed in the State, and cooperate with any agency of the State or Federal government developing plans affecting any watershed of the State; review plans for the development, management and use of the water resources of the State by any State or local agency; make a study of the laws of the State, and other States, and of the Federal government relating to conservation and development of water resources, stream control, watershed development, flood control, and stream pollution to determine the necessity or advisability of the enactment of new or amendatory legislation in the State on such subjects (1955 Supplement, Section 74-2608). [5]

There are a number of miscellaneous statutes protecting water supplies in the State. It is unlawful for anyone to permit salt water, oil or refuse from any well to escape by overflow, seepage, or otherwise (1955 Supplement, Section 55-121). [5] Before abandoning any well drilled for gas or oil, it is the duty of the owner or operator to shut off and exclude all water from entering oil-bearing or gas-bearing sand, strata, or formation encountered in the well, and to use every effort to protect any underground or surface water suitable for domestic or irrigation purposes from infiltration or addition of any detrimental substances, in accordance with methods, rules and regulations adopted and promulgated by the State Corporation Commission and under its direction (1955 Supplement, Section 55-128) [5]

It is unlawful for anyone who disposes below the surface of the earth, salt water mineralized brine, oil, or refuse produced from any oil well, to dispose of same at a pressure in excess of the maximum pressure established by the State Board of Health. Violation is a misdemeanor (1955 Supplement, Section 55-1004). [5]

Operators of oil or gas wells producing salt water, or waters containing minerals in an appreciable degree, have the right to return said waters to any horizon from which produced, or to any other horizon which contains or had previously produced salt water, provided they have received approval to do so from the State Corporation Commission. Violation is a misdemeanor (Section 55-901, 902). [5]

It is unlawful to wilfully poison any spring, well, or reservoir of water (Section 21-433). [5]

Oklahoma

The State Board of Health in Oklahoma has the statutory function of controlling water pollution in the State, including municipal, domestic, or household wastes; it makes rules and regulations to carry out this function. The State Commissioner of Health, through the State Department of Health, administers and enforces the rules and regulations of the board (Title 63, Sections 1.3, 4, 613, 614, 615, 625.3). [6]

Pollution resulting from the production of oil and gas products are controlled by the Corporation Commission (1957 Supplement, Title 52, Sections 139, 145). [6] The Corporation Commission is authorized to make and enforce rules, regulations, and orders governing the handling, storage, and disposition of salt water, mineral brines, waste oil, and other deleterious substances produced from, or used in connection with, the production of oil and gas products, or operation of oil or gas wells for the purpose of preventing water pollution. Any rule, regulation or order relating to or requiring a change of conditions existing as of the date thereof, must grant a reasonable time, not to exceed six months within which to comply before being in violation. The Oklahoma Water Resources Board and the State Game and Fish Department are required to assist and cooperate with the Corporation Commission in the performance of its duties under the Act, by making investigations, gathering evidence, and filing reports or complaints with the commission concerning conditions with respect to the handling, storage, and disposition of deleterious substances, and by making recommendations from time to time to the Commission with respect to rules, regulations, orders, or other action that may be required to carry out the purposes of the Act.

The Water Resources Board makes studies, investigations, conducts research and demonstrations as to the causes, prevention, control and abatement of water pollution; adopts and promulgates standards for water quality, and to classify waters; reviews plans and specifications and issues permits; holds hearing and issues orders; cooperates with Federal and State agencies and private industries in carrying out its purposes and accepts and administers loans and grants from them; adopts, promulgates, and enforces rules and regulations, implementing its powers and duties under the Act (1957 Supplement, Title 82, Sections 903-916, 1073). 6/

The Water Resources Board's responsibility for controlling water pollution does not extend to wastes from oil and gas wells. However, it is authorized to assist and cooperate with the Corporation Commission in this regard, as indicated above.

There are other miscellaneous statutes protecting available waters. Anyone who wilfully and maliciously deposits excrements, or foul or decaying matter into or in any manner corrupts any sources of water used for domestic purposes, or destroys or injures any pipe, conductor of water, or other property pertaining to an aqueduct, or aids or abets in such trespass, may be punished by a fine of not less than $25.00, nor more than $100.00, or by imprisonment for not more than 30 days in jail, or by both (Title 63, Section 27). 6/

Every person who wilfully poisons any spring, well or reservoir of water, is punishable by imprisonment in the penitentiary not exceeding ten years, or in a county jail not exceeding one year, or by a fine not exceeding $500.00, or by both such fine and imprisonment (Title 21, Section 832). 6/

The throwing or depositing of any gas tar, or refuse of any gas house or factory, into any public waters, or into any sewer or stream emptying into such waters is a misdemeanor (Title 21, Section 1194). 6/

No inflammable product from any oil or gas well is to be permitted to run into any tank, pool, or stream used for watering stock, and all waste of oil and refuse from tanks or wells must be drained into proper receptacles at a safe distance from the tanks, wells or building, and be immediately burned or transported from the premises, and in no case must it be permitted to flow over the land. Salt water is not to be allowed to flow over the surface of the land (Title 52, Section 296). 6/

It is unlawful for any person to pollute, or permit the pollution, by salt water, crude oil, or the bottom settlings thereof, by sulphur water, any other mineral water, by the refuse or the products of any well or mine, of any stream, pond, spring, lake, or other water reservoir used as a water supply by any incorporated city or town by which said water is rendered unfit for such use. Any incorporated city or town has a right of action for damages resulting from such pollution (Title 82, Sections 901, 902). 6/

Cities and towns securing their water supply from a stream or reservoir located outside of their corporate limits have power to create a water district, and are empowered to enforce rules and regulations made by the State Commissioner of Health, the county superintendent of public health, or the city superintendent of public health, for the protection of any such water supply (Title 11, Section 298). [6]

Texas

The Texas Water Pollution Control Board [7] is responsible for the control, prevention, and abatement of pollution of the surface and underground waters of the State. Director of the Water Pollution Control Division of the State Department of Health is the Executive Secretary.

The State Department of Health is charged with the responsibility of protecting the public water supplies and passing on sewage disposal systems in order to protect such supplies (Article 4477-1, Sections 5, 10, 12, 13, 20; 1957 Cumulative Supplement, Article 4477-1, Section 5). [8]

The Texas Water Commission makes rules and regulations for, among other things, the drilling, plugging, and casing of wells to prevent salt water or other substances injurious to vegetation or agriculture from escaping into any other water bearing strata, or the surface of the ground (*Penal Code*, Article 848a). [7]

The Railroad Commission is authorized to make rules and regulations in connection with the operation, abandonment and proper plugging of oil and gas wells to prevent the pollution of State surface and subsurface waters (1957 Cumulative Supplement, Article 6029a). [8]

The Commissioner of the General Land Office is authorized to adopt rules and regulations for the prevention of pollution of State waters by persons engaging in oil and gas development in water, on islands, river beds, and channels. The commissioner can call on the Game, Fish, and Oyster Commissioner for assistance in the adoption and enforcement of such rules and regulations. The commissioner can also cancel a permit or lease for failure of an owner to comply with the rules and regulations (Article 5351). [7] The commissioner also makes rules and regulations for the prevention of pollution from oil and gas operations on gulf lands (Article 5366). [7]

There are other miscellaneous statutes which provide protection for State water. It is a misdemeanor for anyone to throw waste paper, glass, metal, garbage, or any other noxious or poisonous substances detrimental to fish or to persons fishing into the waters, or near the waters of Lake Lavon, Collin County (Laws of Texas, 1956, Chapter 55). 8/

The Texas Water Commission is authorized and directed to study all salt springs, gypsum beds, and other sources of natural pollution to tributaries of the Red River; and to study means of elimination such natural pollution, and to prevent such pollution from reaching the Red River (Laws of Texas, 1957, Chapter 362). 8/

It is unlawful for anyone to pollute any public water by depositing therein any crude petroleum, oil or other like substance, or to pollute any such waters which are used for livestock, drinking and domestic purposes, by the discharge of any sewage or other polluting matter therein. This article does not apply to any place or manufacturing plant whose effluents contain no organic matter that will putrify, any poisonous compounds, or any bacteria dangerous to public health or destructive of the fish life of streams or other public bodies of water. The State Board of Health enforces this Act when it affects the public health, and the Game, Fish, and Oyster Commissioner enforces the Act when it affects fish and oysters (Article 4444). 7/

Arkansas

The Arkansas Water Pollution Control Commission, established under the 1949 State Water Pollution Control Act, is responsible for the administration and enforcement of all laws relating to the pollution of waters of the State. The commission is set up within the State Board of Health, but by statute it acts independently of the board, and its members are named by a number of State agencies and by the Governor to represent a variety of interests. The broad authority of the Water Pollution Control Commission to control and abate stream pollution through development of a comprehensive program extends to all streams and lakes within, or bordering, the State, and to underground waters, marshes, watercourses, drainage systems, and natural or artificial, public or private, bodies of water, the pollution of which may create a nuisance, or be actually or potentially harmful or detrimental to public health, safety, or welfare, or to domestic, commercial, industrial, agricultural, or recreational uses, or to livestock or wildlife (Title 47, 1955 Cumulative Supplement, Sections 802-810). 9/

The State Board of Health has general supervision and control of all matters pertaining to the health of the citizens, including direction and control over all sanitary measures for dealing with infectious, contagious, and communicable diseases within the State. It may make all necessary and reasonable rules and regulations of a general nature for the protection of the public health, and for the improvement of sanitary and hygenic conditions within the State

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(Title 82, Sections 109, 110).[9] The Board of Health is required to adopt rules and regulations pertaining specifically to the control of industrial health hazards, including those related to water supplies and sewage disposal facilities (Title 81, Section 417).[9] The secretary of the Board of Health must issue certificates of approval of all plans and specifications in waterworks and sewer improvement districts (Title 20, Section 302).[9]

The Arkansas Game and Fish Commission has authority in the field of water pollution, which in many respects is parallel to the Water Pollution Control Commission. The Game and Fish Commission is authorized to control the disposal of wastes into the waters of the State by municipalities, industries, and public and private persons if detrimental to fish and other aquatic life; to establish pollution standards for such waters; to restrain the discharge of waste material or polluting substances into State waters; to issue rules, regulations, and orders in carrying out these functions, and also to abate existing pollution independently of any action which may be taken by any other State agency (Title 47, Section 801; Title 47, 1955 Cumulative Supplement, Sections 811-813).[9]

The Arkansas Geological and Conservation Commission, which succeeded to some of the functions of the former Resources and Development Commission, is responsible for preparing and adopting an official State plan for the physical development of the State (Title 9, Section 114).[9] This plan is to contain recommendations for the development of the State which may cover, among other things, the general location, character, and extent of waterways, drainage, and sanitary systems, and works for the prevention of stream pollution (Title 9, Section 301).[9] After the adoption of an official State plan by the Geological and Conservation Commission, the commission has review and advisory authority as to the location, character, and extent of proposed improvements, building, structures, or property which may be acquired by any State or public agency (Title 9, Section 305).[9] The Geological and Conservation Commission also has authority to control, preserve, and regulate the flow of rivers and streams (Title 9, Section 803).[9]

The Arkansas Oil and Gas Commission, consisting of seven members appointed by the Governor, is authorized to make, after hearing and notice, necessary rules, regulations, or orders "to prevent the pollution of fresh water supplies by oil, gas, or salt water" (Title 53, Section 111).[9]

The Governor of Arkansas may appoint five members to the Arkansas Water Compact Commission which is authorized to negotiate, with representatives of adjoining states, compacts governing the protection and use of interstate waters (Title 21, Section 1201).[9]

Miscellaneous provisions for protection of the water supplies are made in the statutes.

Pollution of water or injury to water supplies or waterworks are prohibited (Title 19, Section 2317). [9]

Committing a nuisance in or near an impounding dam or reservoir of a water plant, or polluting or affecting the wholesome qualities of water in such dams or reservoirs, are misdemeanors punishable by a fine not exceeding $200.00 (Title 35, Section 407). [9]

Louisiana

In Louisiana, the Stream Control Commission has the primary function of controlling water pollution. The commission establishes pollution standards for the waters of the State (Section 56:1439).[10] It controls waste disposal, public or private, into the waters of the State (Section 56:1434). [10] No one may discharge, or permit to be discharged, into any of the waters of the State any pollution of any kind that will tend to destroy fish, other aquatic life, wild or domestic animals, or fowls, or be injurious to the public health or against the public welfare in violation of any rule, order or regulation of the commission (Section 56:1440). [10]

The State Board of Health, in addition to its general powers to provide for the health of the people, exercises jurisdiction over the water supplies of the State (Section 40:11). [10]

The Commissioner of Conservation is authorized to make rules, regulations and orders for, among other things, the drilling, casing and plugging of wells to prevent the escape of oil or gas out of one stratum to another; the prevention of the intrusion of water into oil or gas strata; and the prevention of the pollution of fresh water supplies by oil, gas, or salt water (Section 56:1452). [10]

"Waters of the state" includes river, streams, lakes, and all other watercourses and waters within the confines of the State, and all bordering waters, including the Gulf of Mexico.

A number of miscellaneous statutory provisions protect the water supplies. It is unlawful:

1. To contaminate a water supply. Violation carries a fine or imprisonment or both (Section 14:58). [10]

2. To knowingly and willfully drain from any pump, reservoir, well or oilfield into any natural stream used for irrigation purposes, any oil, salt water, or other noxious or poisonous wastes which would render the water unfit

for irrigation purposes or would destroy fish, except during the open season between October 1 and December 31, inclusive. This prohibition does not prevent:

a. The discharge of brine from industrial, oil, or mining operations into those portions of natural streams and drains having water which has a normal salt content of more than 110 grains per gallon (1,700 ppm), to be determined by the daily average for the preceding ten years, measured at any depth not to exceed 12½ feet, or into tributaries of such streams which empty into the portions thereof which are excluded from the effect hereof; such water being hereby recognized as unfit for irrigation; and,

b. The discharge or drainage of salt water, brine, chemical salts, chemicals, solids, or any other substances from industrial, oil or mining operations into any stream having its source outside the State, or into any tributary thereof (1956 Cumulative Supplement, Section 38:216). 10/

3. To abandon a well in, or adjacent to, a natural gas field without first placing a properly made plug both above and below the gas-producing sand, or otherwise sufficiently securing the well against the admission of water into the gas-producing sand. Violation carries a fine or imprisonment, or both (Section 30:34). 10/

4. To discharge, or permit to be discharged, into any waters of the State, or into drains which discharge into such waters, any substance which kills fish, or renders the water unfit for the maintenance of the normal fish life characteristic of the waters, or in any way adversely affects the interest of the State. Each day the violation continues is a separate offense (Sections 56:322, 362). 10/

Prior written consent of the Director of Highways and the State Board of Health must be obtained before anyone is permitted to discharge industrial wastes, sewage, septic tanks effluent, or harmful matter into the side or cross ditches, or upon the rights of the State highways (Section 48:385). 10/

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10. West's Louisiana Statutes Annotated, Revised Statutes 1950, and the 1956 Cumulative Supplement.

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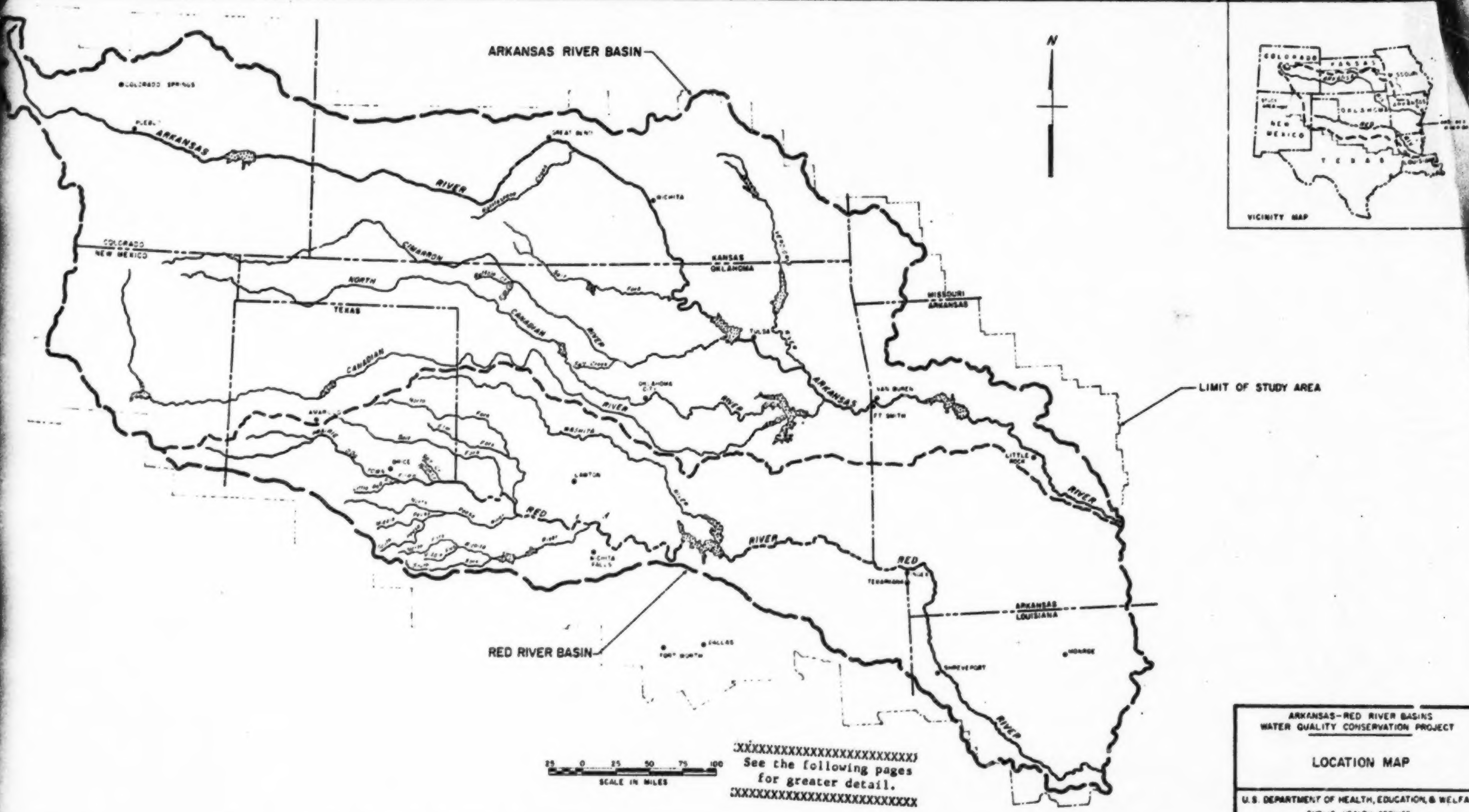
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See the following pages
for greater detail.
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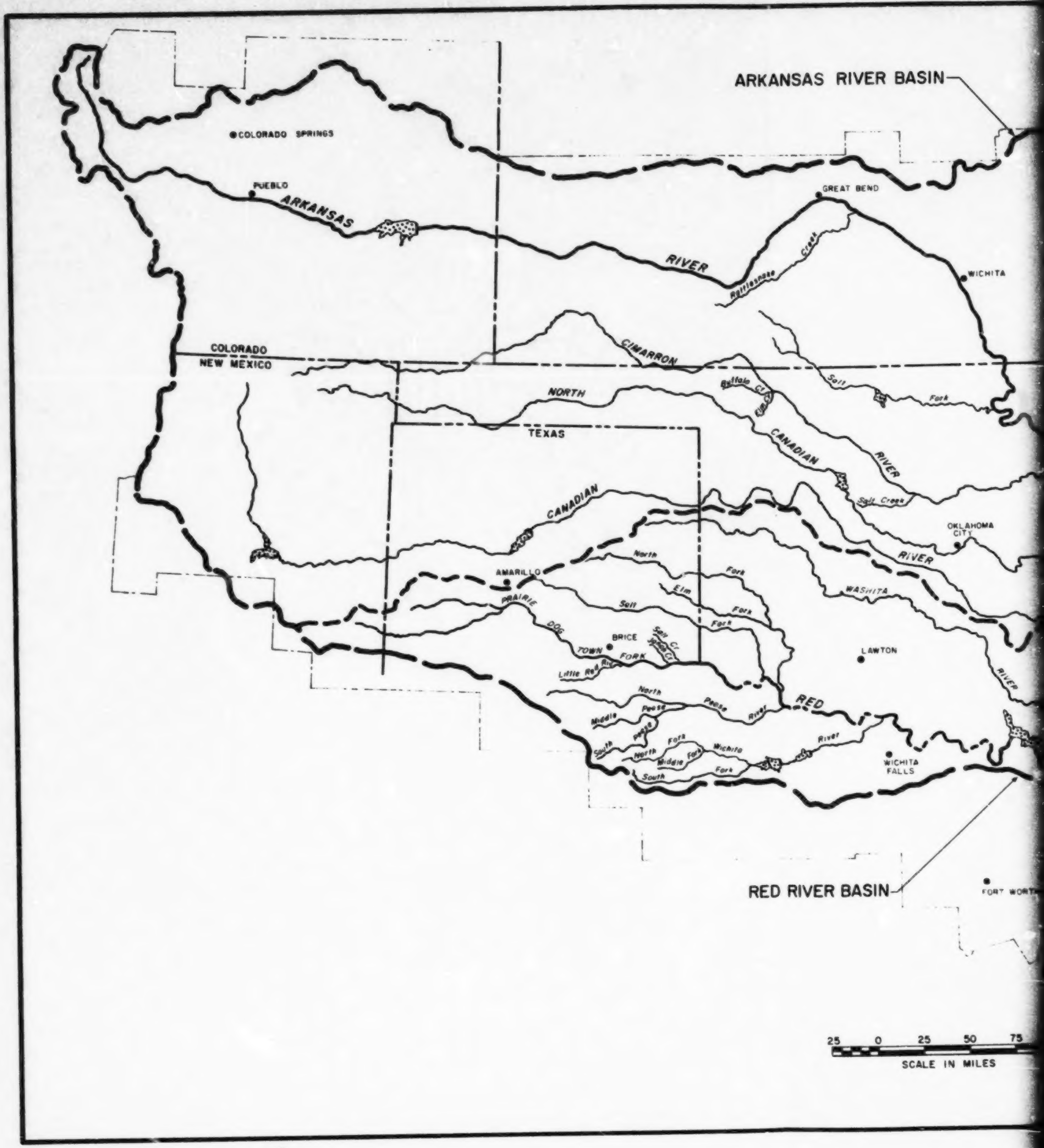
ARKANSAS-RED RIVER BASINS
WATER QUALITY CONSERVATION PROJECT

LOCATION MAP

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE

FIGURE 1-1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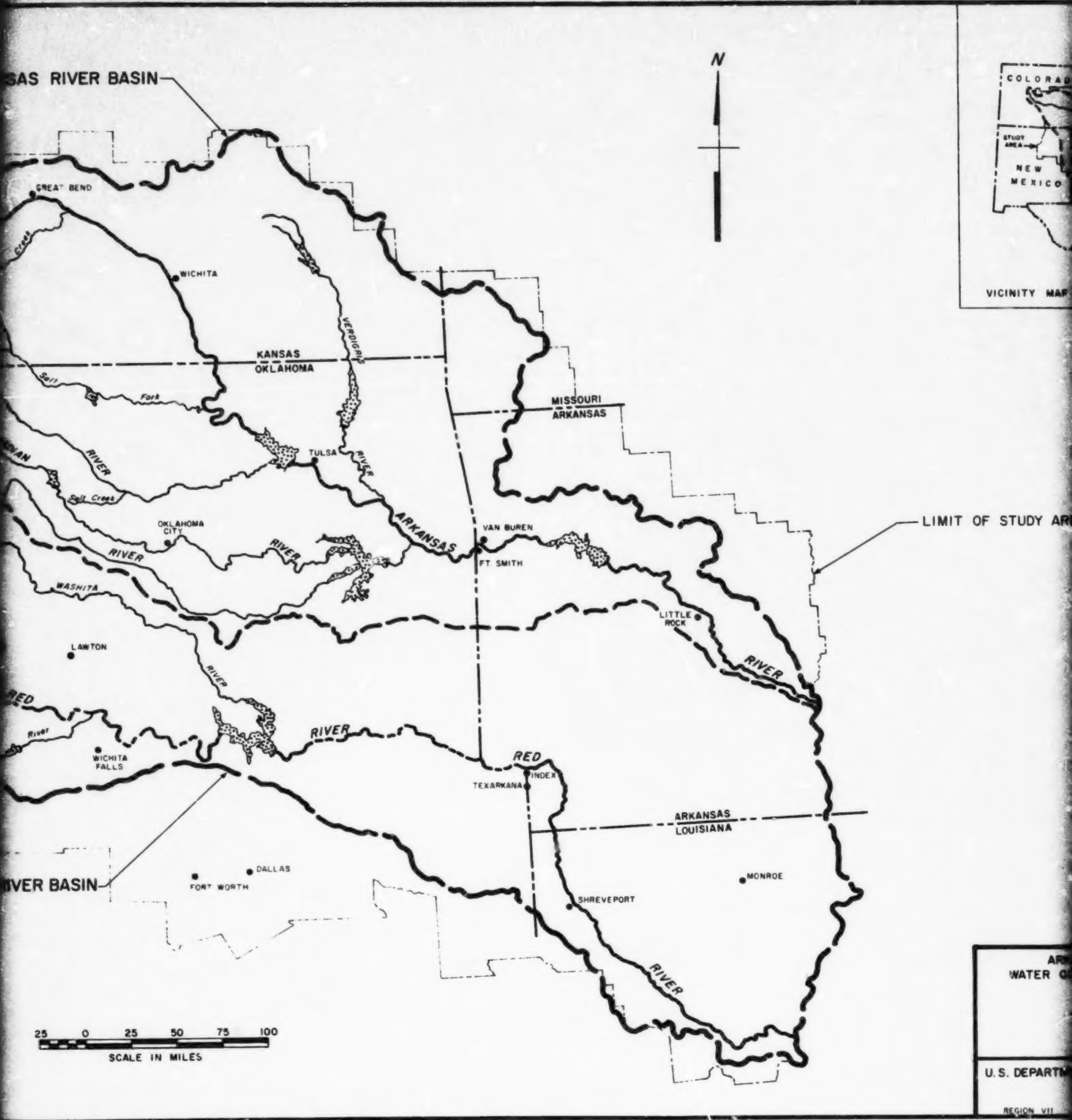
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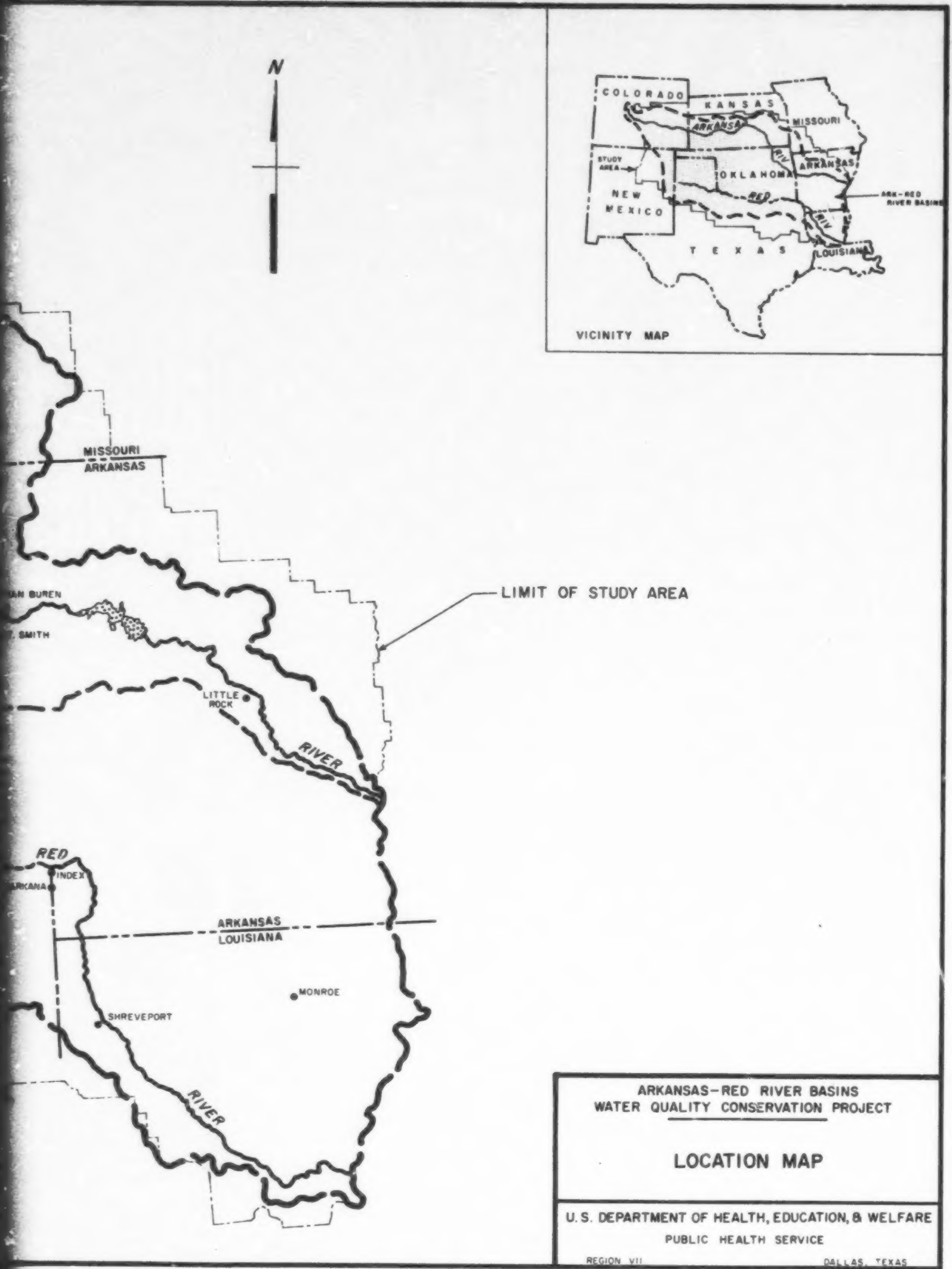
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ARKANSAS-RED RIVER BASINS
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LOCATION MAP

U.S. DEPARTMENT OF HEALTH, EDUCATION, & WELFARE
PUBLIC HEALTH SERVICE
REGION VII DALLAS, TEXAS

FIGURE I-1

C